

## OPTIMAL CONTROL OF LINEARIZED COMPRESSIBLE NAVIER-STOKES EQUATIONS

SHIRSHENDU CHOWDHURY<sup>1</sup> AND MYTHILY RAMASWAMY<sup>1</sup>

**Abstract.** We study an optimal boundary control problem for the two dimensional unsteady linearized compressible Navier–Stokes equations in a rectangle. The control acts through the Dirichlet boundary condition. We first establish the existence and uniqueness of the solution for the two-dimensional unsteady linearized compressible Navier–Stokes equations in a rectangle with inhomogeneous Dirichlet boundary data, not necessarily smooth. Then, we prove the existence and uniqueness of the optimal solution over the control set. Finally we derive an optimality system from which the optimal solution can be determined.

**Mathematics Subject Classification.** 49J20, 49K20, 35Q30, 76N25.

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### 1. INTRODUCTION

The Navier–Stokes equations for a viscous compressible isentropic fluid in  $\Omega \subset \mathbb{R}^N$  is

$$\left. \begin{aligned} \frac{\partial \rho}{\partial t}(t, x) + \operatorname{div}[\rho(t, x)\mathbf{v}(t, x)] &= 0, \\ \rho(t, x) \left[ \frac{\partial \mathbf{v}}{\partial t}(t, x) + (\mathbf{v}(t, x) \cdot \nabla) \mathbf{v}(t, x) \right] &= -\nabla p(t, x) + \mu \Delta \mathbf{v}(t, x) + (\lambda + \mu) \nabla [\operatorname{div} \mathbf{v}(t, x)], \\ p(t, x) &= ap^\gamma(t, x), \quad t > 0, \quad x \in \Omega, \end{aligned} \right\} \quad (1.1)$$

where  $\rho(t, x)$  is the density of the fluid,  $\mathbf{v}(t, x) = (v_1(t, x), \dots, v_N(t, x))$  denotes the velocity vector in  $\mathbb{R}^N$  and  $p(t, x)$  denotes the pressure. Note that the second equation of (1.1) componentwise is

$$\rho \left( \frac{\partial v_i}{\partial t} + \mathbf{v} \cdot \nabla v_i \right) = -\frac{\partial p}{\partial x_i} + \mu \Delta v_i + (\lambda + \mu) \frac{\partial}{\partial x_i} [\operatorname{div} \mathbf{v}], i = 1, 2, \dots, N.$$

Throughout this paper, we follow this same notational convention and use bold script to denote vectors and product spaces. The viscosity coefficients  $\mu, \lambda$  are assumed to be constant satisfying the following thermodynamic restrictions:  $\mu > 0$ ,  $\lambda + \mu \geq 0$  and the constants  $a > 0$ ,  $\gamma > 1$ .

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# Numerical Solution Of The Incomprebible Navierstokes Equations Vol 113

**JA Banks**



## **Numerical Solution Of The Incompressible Navier-Stokes Equations Vol 113:**

Projection and Quasi-Compressibility Methods for Solving the Incompressible Navier-Stokes Equations, 2013-11-11

Projection methods had been introduced in the late sixties by A Chorin and R Teman to decouple the computation of velocity and pressure within the time stepping for solving the nonstationary Navier Stokes equations Despite the good performance of projection methods in practical computations their success remained somewhat mysterious as the operator splitting implicitly introduces a nonphysical boundary condition for the pressure The objectives of this monograph are twofold First a rigorous error analysis is presented for existing projection methods by means of relating them to so called quasi compressibility methods e g penalty method pressure stabilization method etc This approach highlights the intrinsic error mechanisms of these schemes and explains the reasons for their limitations Then in the second part more sophisticated new schemes are constructed and analyzed which are exempted from most of the deficiencies of the classical projection and quasi compressibility methods this book should be mandatory reading for applied mathematicians specializing in computational fluid dynamics J L Guermond Mathematical Reviews Ann Arbor

**Incompressible Flow** Ronald L. Panton, 2013-07-18 The most teachable book on incompressible flow now fully revised updated and expanded Incompressible Flow Fourth Edition is the updated and revised edition of Ronald Panton's classic text It continues a respected tradition of providing the most comprehensive coverage of the subject in an exceptionally clear unified and carefully paced introduction to advanced concepts in fluid mechanics Beginning with basic principles this Fourth Edition patiently develops the math and physics leading to major theories Throughout the book provides a unified presentation of physics mathematics and engineering applications liberally supplemented with helpful exercises and example problems Revised to reflect students ready access to mathematical computer programs that have advanced features and are easy to use Incompressible Flow Fourth Edition includes Several more exact solutions of the Navier Stokes equations Classic style Fortran programs for the Hiemenz flow the Psi Omega method for entrance flow and the laminar boundary layer program all revised into MATLAB A new discussion of the global vorticity boundary restriction A revised vorticity dynamics chapter with new examples including the ring line vortex and the Fraenkel Norbury vortex solutions A discussion of the different behaviors that occur in subsonic and supersonic steady flows Additional emphasis on composite asymptotic expansions Incompressible Flow Fourth Edition is the ideal coursebook for classes in fluid dynamics offered in mechanical aerospace and chemical engineering programs

Finite Element Methods for Flow Problems Jean Donea, Antonio Huerta, 2003-06-02 In recent years there have been significant developments in the development of stable and accurate finite element procedures for the numerical approximation of a wide range of fluid mechanics problems Taking an engineering rather than a mathematical bias this valuable reference resource details the fundamentals of stabilised finite element methods for the analysis of steady and time dependent fluid dynamics problems Organised into six chapters this text combines theoretical aspects and practical applications and offers coverage of

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Computational Fluid Dynamics Review 1998 (In 2 Volumes) Mohamed M Hafez,Koichhi Oshima,1998-11-20 The first volume of CFD Review was published in 1995 The purpose of this new publication is to present comprehensive surveys and review articles which provide up to date information about recent progress in computational fluid dynamics on a regular basis Because of the multidisciplinary nature of CFD it is difficult to cope with all the important developments in related areas There are at least ten regular international conferences dealing with different aspects of CFD It is a real challenge to keep up with all these activities and to be aware of essential and fundamental contributions in these areas It is hoped that CFD Review will help in this regard by covering the state of the art in this field The present book contains sixty two articles written by authors from the US Europe Japan and China covering the main aspects of CFD There are five sections general topics numerical methods flow physics interdisciplinary applications parallel computation and flow visualization The section on numerical methods includes grids schemes and solvers while that on flow physics includes incompressible and compressible flows hypersonics and gas kinetics as well as transition and turbulence This book should be useful to all researchers in this fast developing field

Mathematical Aspects of Discontinuous Galerkin Methods Daniele Antonio Di Pietro,Alexandre Ern,2011-11-03 This book introduces the basic ideas to build discontinuous Galerkin methods and at the same time incorporates several recent mathematical developments The presentation is to a large extent self contained and is intended for graduate students and researchers in numerical analysis The material covers a wide range of model problems both steady and unsteady elaborating from advection reaction and diffusion problems up to the Navier Stokes equations and Friedrichs systems Both finite element and finite volume viewpoints are exploited to convey the main ideas underlying the design of the approximation The analysis is presented in a rigorous mathematical setting where discrete counterparts of the key properties of the continuous problem are identified The framework encompasses fairly general meshes regarding element shapes and hanging nodes Salient implementation issues are also addressed

*High Performance Computing for Computational Science - VECPAR 2004* Michel Daydé,2005-04-28 This book constitutes the thoroughly refereed post proceedings of the 6th International Conference on High Performance Computing for Computational Science VECPAR 2004 held in Valencia Spain in June 2004 The 48 revised full papers presented together with 5 invited papers were carefully selected during two rounds of reviewing and improvement from initially 130 contributions The papers are organized in topical sections on large scale computations data management and data mining GRID computing infrastructure cluster

computing parallel and distributed computing and computational linear and non linear algebra      Thermal Convection

Marcello Lappa, 2009-11-05 Thermal Convection Patterns Stages of Evolution and Stability Behavior provides the reader with an ensemble picture of the subject illustrating the state of the art and providing the researchers from universities and industry with a basis on which they are able to estimate the possible impact of a variety of parameters Unlike earlier books on the subject the heavy mathematical background underlying and governing the behaviors illustrated in the text are kept to a minimum The text clarifies some still unresolved controversies pertaining to the physical nature of the dominating driving force responsible for asymmetric oscillatory convection in various natural phenomena and or technologically important processes and can help researchers in elaborating and validating new more complex models in accelerating the current trend towards predictable and reproducible natural phenomena and in establishing an adequate scientific foundation to industrial processes Thermal Convection Patterns Stages of Evolution and Stability Behavior is intended as a useful reference guide for specialists in disciplines such as the metallurgy and foundry field and researchers and scientists who are now coordinating their efforts to improve the quality of semiconductor or macromolecular crystals The text may also be of use to organic chemists and materials scientists atmosphere and planetary physicists as well as an advanced level text for students taking part in courses on the physics of fluids fluid mechanics the behavior and evolution of non linear systems environmental phenomena and materials engineering      **Flow Simulation with High-Performance Computers II** Ernst Heinrich Hirschel, 2013-04-17 Der Band enth lt den Abschlus bericht des DFG Schwerpunktprogramms Flu simulation mit Hochleistungsrechnern Es f hrt die Arbeiten fort die schon als Band 38 in der Reihe Notes on Numerical Fluid Mechanics erschienen sind Work is reported which was sponsored by the Deutsche Forschungsgemeinschaft from 1993 to 1995 Scientists from numerical mathematics fluid mechanics aerodynamics and turbomachinery present their work on flow simulation with massively parallel systems on the direct and large eddy simulation of turbulence and on mathematical foundations general solution techniques and applications Results are reported from benchmark computations of laminar flow around a cylinder in which seventeen groups participated      Riemann Solvers and Numerical Methods for Fluid Dynamics

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**Nonlinear Dynamics and Applications** Santo Banerjee,Asit Saha,2022-10-06 This book covers recent trends and applications of nonlinear dynamics in various branches of society science and engineering The selected peer reviewed contributions were presented at the International Conference on Nonlinear Dynamics and Applications ICNDA 2022 at Sikkim Manipal Institute of Technology SMIT and cover a broad swath of topics ranging from chaos theory and fractals to quantum systems and the dynamics of the COVID 19 pandemic Organized by the SMIT Department of Mathematics this international conference offers an interdisciplinary stage for scientists researchers and inventors to present and discuss the latest innovations and trends in all possible areas of nonlinear dynamics *Recent Advances in Scientific Computing and Applications* Jichun Li,Hongtao Yang,Eric Alexander Machorro,2013-04-24 This volume contains the proceedings of the Eighth International Conference on Scientific Computing and Applications held April 1 4 2012 at the University of Nevada

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Minev,Yanping Lin,2001 Scientific Computing Applications **A Structured-grid Adaptive Mesh Refinement Multigrid Algorithm for Steady-state Flows** Scott Andrew Dudek,1996 Fundamental Directions in Mathematical Fluid Mechanics

Giovanni P. Galdi,John G. Heywood,Rolf Rannacher,2012-12-06 This volume consists of six articles each treating an important topic in the theory of the Navier Stokes equations at the research level Some of the articles are mainly expository putting together in a unified setting the results of recent research papers and conference lectures Several other articles are devoted mainly to new results but present them within a wider context and with a fuller exposition than is usual for journals The plan to publish these articles as a book began with the lecture notes for the short courses of G P Galdi and R Rannacher given at the beginning of the International Workshop on Theoretical and Numerical Fluid Dynamics held in Vancouver Canada July 27 to August 2 1996 A renewed energy for this project came with the founding of the Journal of Mathematical Fluid Mechanics by G P Galdi J Heywood and R Rannacher in 1998 At that time it was decided that this volume should be published in association with the journal and expanded to include articles by J Heywood and W Nagata J Heywood and M Padula and P Gervasio A Quarteroni and F Saleri The original lecture notes were also revised and updated **Navier-stokes Equations**

**In Planar Domains** Matania Ben-artzi,Jean Pierre Croisille,Dalia Fishelov,2013-03-07 This volume deals with the classical Navier Stokes system of equations governing the planar flow of incompressible viscous fluid It is a first of its kind book devoted to all aspects of the study of such flows ranging from theoretical to numerical including detailed accounts of classical test problems such as driven cavity and double driven cavity A comprehensive treatment of the mathematical theory

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