Contents

1	Intr	duction	1			
2	Partial Differential Equations in Mathematical Modeling of Fluid					
	Flor	Problems	- 5			
	2.1	Introduction	5			
		2.1.1 The Navier-Stokes Equations for Compressible Viscous				
		Flow	12			
		2.1.2 The Euler Equations for Compressible Inviscid Flow	12			
		2.1.3 Vector Form of the Navier-Stokes Equations for				
		Compressible Viscous Flow	13			
	2.2	Non-dimensionalization	14			
	2.3	Turbulence and Its Modeling	14			
		2.3.1 Turbulent Averaged Quantities	15			
		2.3.2 The Reynolds Averaged Navier-Stokes Equations	16			
	2.4	Analytic Aspects of the PDEs	17			
3	PDI	Constrained Optimization Methods	19			
	3.1	Unconstrained Optimization Problem	19			
	3.2	Constrained Optimization Problem	21			
		3.2.1 Nested Analysis and Design (NAND)	21			
		3.2.2 Simultaneous Analysis and Design (SAND)	24			
		3.2.3 Full Newton SAND	24			
Pai	t I: A	plications in Environmental Engineering				
4	Mat	ematical Model of Multiphase Flow through Porous Media	29			
	4.1	Introduction	29			
4.2 General form of the Multiphase Flow Equations						
		4.2.1 Isothermal Water-Gas System (Two-Phase Flow)	30 31			



		4.2.2 Nonisothermal Water-Gas Systems (Two-Phase	
		Two-Component Flow)	32
		4.2.3 Constitutive Relationships	34
	4.3	The Forward Simulation Problem	36
		4.3.1 Governing Equations	36
	4.4	Discretization	38
		4.4.1 Implicit Time Discretization	40
	4.5	The Software System MUFTE_UG	41
5	Para	ameter Identification in Multiphase Flow through Porous	
	Med	lia	43
	5.1	Introduction	43
	5.2	Least-Squares Formulation	44
	5.3	The Multiple Shooting Parameter Estimation Approach	44
	5.4	A Reduced Generalized Gauss-Newton Method	45
	5.5	Computation of (Inexact) Derivatives	47
	5.6	Numerical Results and Discussion	50
		5.6.1 Isothermal Case (Two-Phase flow)	50
		5.6.2 Non-isothermal Case (Two-Phase Two-Component	
		Flow)	52
	5.7	Conclusions	61
Par	t II: A	Applications in Aerodynamics	
6		ultaneous Pseudo-Time-Stepping for PDE-Model Based	65
	-	imization Problems	65
	6.1	Introduction	03
	6.2	The Optimization Problem and Pseudo-unsteady Formulation of the KKT Conditions	67
	6.3	Reduced SQP Methods	69
	6.4	Pseudo-Time-Stepping for Optimization Problems	71
	6.5	Application to a Model Problem	72
	6.6		73
		Analysis of the Hessian	75
	6.7	Numerical Implementation	
	6.8	Results and Discussion	76
	6.9	Conclusions	80
7		odynamic Shape Optimization Using Simultaneous	
	Pseu	ıdo-Time-Stepping	81
	7.1	Introduction	81
	7.2	Pseudo-Time-Stepping for Optimization Problems	83
	7.3	Detailed Equations of the Aerodynamic Shape Optimization	
		Problem in 2D	83
	7.4	Discretization	86
	7.5	Reduced Hessian Updates	92

Contents XI

		7.6.1	Drag Reduction with Geometric Constraint for an								
			RAE2822 Airfoil	95							
		7.6.2	Drag Reduction with Geometric Constraints for								
			Supersonic Cruise Transport (SCT) Wing	102							
	7.7	Concl	usions	104							
8	Indirect Treatment of State Constraints in Aerodynamic Shape										
			on Using Simultaneous Pseudo-Time-Stepping	105							
	8.1		uction	105							
	8.2		o-Time-Stepping for the Constrained Optimization								
			em	105							
	8.3	Nume	rical Results and Discussion	109							
	8.4		usions	116							
9	Dire	ct Trea	atment of State Constraints in Aerodynamic Shape								
			on Using Simultaneous Pseudo-Time-Stepping	117							
	9.1		uction	117							
	9.2		State Constraints	118							
		9.2.1	Partial Reduction of the Problem	119							
		9.2.2	Solution Strategy of the Constrained Problem	120							
		9.2.3	Back Projection	121							
	9.3	Nume	rical Results and Discussion	122							
		9.3.1	Applications in 2D	123							
		9.3.2	Application in 3D	127							
	9.4	Concl	usions	132							
10	Mul	Multigrid One-Shot Pseudo-Time-Stepping Method for									
			nic Shape Optimization	135							
		•	uction	135							
	10.2	The M	Iultigrid Algorithm	136							
			rical Results and Discussion	137							
		10.3.1	Drag Reduction with Constant Thickness for RAE2822								
			Airfoil	137							
		10.3.2	Drag Reduction with Geometric Constraints for								
			SCT Wing	147							
	10.4	Concl	usions	152							
11	Mul	tigrid (One-Shot Pseudo-Time-Stepping Method for State								
			d Aerodynamic Shape Optimization	155							
			uction	155							
	11.2	The M	lultigrid Algorithm	156							
			rical Results and Discussions	157							
		11.3.1	Drag Reduction with Constant Lift on (193×33) Grid	158							
		11.3.2	Drag Reduction with Constant Lift on (321×57) Grid	164							
	114	Conch	ueione	173							

XII Contents

12	One-Shot Pseudo-Time-Stepping Method for Aerodynamic				
	Shape Optimization Using the Navier-Stokes Equations				
	12.1	Introduction	175		
	12.2	Detailed Equations of the Aerodynamic Shape Optimization			
		Problem	176		
	12.3	Numerical Results and Discussion	183		
	12.4	Conclusions	188		
Ref	erenc	es	189		
Ind	ex		199		