

Contents

1. Introduction	1
2. General Theory of Nozzle Gas Flows	6
2.1 Basic Equations and Problem Formulation	6
2.1.1 Basic Equations	7
2.1.2 Characteristics	12
2.1.3 The Direct Problem	28
2.1.4 The Inverse Problem	32
2.2 Some Elementary Theories	40
2.2.1 One-Dimensional Theory	41
2.2.2 Radial Flows or Source/Sink Flows	52
2.2.3 Prandtl-Meyer Flow	54
2.3 Variational Problems of Gas Dynamics of Internal Flows	56
3. Numerical Methods of Studying Nozzle Gas Flows	65
3.1 Methods of Solving Relaxation Equations	65
3.2 Methods of Calculating Plane and Axisymmetric Supersonic Flows	69
3.2.1 Method of Characteristics	69
3.2.2 Shock-Smearing Methods	82
3.3 Methods of Calculating Three-Dimensional Supersonic Flows ...	92
3.3.1 Method of Characteristics	93
3.3.2 Difference Methods	97
3.4 Methods of Solving the Inverse Problem of the Theory of Nozzles	100
3.5 Methods of Solving the Direct Problem of the Theory of Nozzles	104
4. Asymptotic Methods in the Theory of Nozzles	110
4.1 Source-Sink Method and Inverse Problem for Incompressible Fluid	110
4.1.1 Plane Flow	111
4.1.2 Axisymmetric Flow	112
4.1.3 Three-Dimensional Flow	113
4.1.4 Solution of the Inverse Problem for Incompressible Fluid	113
4.2 Expansion in a Stream Function Series	114
4.2.1 Three-Dimensional Flow	115
4.2.2 Plane and Axisymmetric Flows	120
4.2.3 Two-Phase Flows	125
4.3 Asymptotic Methods in the Transonic Region	126
4.3.1 Method of Small Perturbations	126
4.3.2 Series Expansion in the Vicinity of a Rectilinear Sonic Line	127

4.4	Solution in the Neighbourhood of the Infinite Point in the Subsonic Region	131
4.5	Method of Small Perturbations for Flows Close to Radial	132
5.	Nozzles of Jet Engines	143
5.1	Flow Peculiarities in the Subsonic and Transonic Parts of a Nozzle	144
5.1.1	Nozzle with a Rectilinear Surface of Transition	145
5.1.2	Nozzle with a Curvilinear Surface of Transition	146
5.1.3	Local Deceleration Zones	151
5.1.4	Optimum Shape of the Subsonic Part of a Nozzle	158
5.1.5	Flow Rate Coefficient and Critical Pressure Drop in Nozzles with Curvilinear Transition Surfaces	159
5.1.6	Profiling of the Acceleration Part of a Jet Engine Nozzle	163
5.2	Profiling of Supersonic Parts of Jet Engine Nozzles and Impulse Losses	165
5.2.1	Profiling of Supersonic Parts of Jet Engine Nozzles	165
5.2.2	Impulse Losses	172
5.2.3	Thrust Changes Caused by Deviations from the Design Flow Regime	188
5.2.4	Numerical and Experimental Simulation of Flows in Jet Engine Nozzles	191
5.3	Main Principles of Choosing a Jet Engine Nozzle	192
6.	Flows with Physico-Chemical Transformations	199
6.1	Isentropic Flows and Intermolecular Interaction	199
6.1.1	Isentropic Flows	199
6.1.2	Intermolecular Interaction	206
6.2	Flows with Nonequilibrium Chemical Reactions	208
6.2.1	Basic Equations, Method of Prediction and the One-Dimensional Approximation	209
6.2.2	Major Characteristic Features of Chemical Nonequilibrium Flows	216
6.2.3	Plane and Axisymmetric Flows	226
6.2.4	Approximate Methods of Calculating Nonequilibrium Flows	230
6.3	Flows with Vibrational Relaxation	231
6.3.1	Relaxation Equations and Methods of Prediction	232
6.3.2	Results of Calculations in the One-Dimensional Approximation	241
6.3.3	Plane and Axisymmetric Flows	244
6.4	Two-Phase Flows	249
6.4.1	Basic Concepts: One-Dimensional Approximation, Equilibrium and Frozen Flows	249
6.4.2	One-Dimensional Nonequilibrium Flows Without Phase Transitions; Impulse Losses	260
6.4.3	One-Dimensional Flows with Interacting Particles	265
6.4.4	One-Dimensional Flows with Phase Transitions	270
6.4.5	Flows in Axisymmetric and Plane Nozzles	289
6.5	Conductive Gas Nozzle Flows in the Presence of an Electromagnetic Field	298
6.6	Multilayer Nozzle Flows	304
6.6.1	One-Dimensional Approximation	304
6.6.2	Axisymmetric Flows	314

7. Special Nozzles, Three-Dimensional Flows, Viscosity Effect	318
7.1 Annular Nozzles and Wind Tunnel Nozzles	318
7.1.1 Some Schemes of Annular Nozzles and Methods of Calculation	318
7.1.2 Off-Design Flow Regimes in Annular Nozzles	328
7.1.3 Wind Tunnel Nozzles	334
7.2 Conical Nozzles	337
7.3 Swirling Nozzle Flows	343
7.3.1 Introductory Notes	344
7.3.2 Radially Balanced Flows	347
7.3.3 Axisymmetric Swirling Flows	356
7.4 Three-Dimensional Nozzle Flows	359
7.4.1 Some Results of Analytical and Experimental Studies .	360
7.4.2 Method of Small Perturbations and Determination of Side Forces and Moments	366
7.4.3 Numerical Investigation of Three-Dimensional Nozzle Gas Flows	379
7.4.4 Experimental Studies of Side Forces and Moments	385
7.5 Flows at Small Reynolds Numbers	394
 Nomenclature	 405
References	411
Subject Index	421