CONTENTS

Contributors **xxv**

Chapter One Aerodynamics **1**

CHAPTER SUMMARY 2

PRELIMINARY RESULTS OF FLOW FLUCTUATION MEASUREMENTS IN THE CRYOGENIC TRANSONIC WIND TUNNEL

V. N. Zinovyev, V. A. Lebiga, A. Yu. Pak, and J. Quest 3

1 Introduction 3
2 Experimental Background 4
3 Results and Discussions 8
4 Concluding Remarks 12
Acknowledgments 13
References 13

TEMPERATURE SENSITIVE PAINT APPLICATION FOR INVESTIGATION OF BOUNDARY LAYER TRANSITION IN SHORT-DURATION WIND TUNNELS

V. Borovoy, V. Mosharov, A. Noev, and V. Radchenko 15

1 Background 15
2 Experimental Facility and the Model 17
3 Measurement System 18
4 Results 19
5 Concluding Remarks 24
Acknowledgments 24
References 24

SIMULATION OF AFTERBODY TRANSONIC FLOWS USING PARTIALLY-AVERAGED NAVIER–STOKES MODEL FOR TURBULENCE

D. Deprés and P. Brenner 25

1 Introduction 25
2 Turbulence Modeling Adapted to Unsteady Flows 26

3 Methodology 28
4 Computational Results 32
5 On a Working Logic to Improve Partially-Averaged Navier–Stokes Calculations 37
6 Concluding Remarks 39
Acknowledgments 39
References 40

FLOW STRUCTURE AND TURBULENCE IN NEAR FIELDS OF CIRCULAR AND NONCIRCULAR JETS
N. E. Öçer, G. Taşar, O. Uzol, and S. Özgen 41
1 Introduction 41
2 Experimental Setup and Methodology 42
3 Results 45
4 Concluding Remarks 51
Acknowledgments 51
References 51

AIRCRAFT DYNAMIC LATERAL STABILITY ANALYTIC FORMULATION FOR DUTCH ROLL MODE STABILITY PREDICTION
M. J. Bazile and M. F. Calderara 53
Nomenclature 53
1 Introduction 54
2 Remind of Some Longitudinal Considerations About Dynamic Stability 54
3 Lateral Flight Mechanic Model 55
4 Lateral Stability Criteria 57
5 Use of the Method for A/C Design Phase 60
6 Concluding Remarks 61
References 62

A JOINT NUMERICAL AND EXPERIMENTAL STUDY OF THE JET OF AN AIRCRAFT ENGINE INSTALLATION WITH ADVANCED TECHNIQUES
V. Brunet, P. Molton, H. Bézard, S. Deck, and L. Jacquin . 63
1 Introduction 63
2 Experimental Setup and Flow Conditions 64
3 Numerical Simulations 67

4 Engine Jet Development 69
5 Concluding Remarks and Perspectives 76
References 77

PROPAGATION OF DISTURBANCE IN BOUNDARY LAYER ON PLANAR DELTA WING IN THE STRONG INTERACTION REGIME
G. N. Dudin 79
1 Formulation of the Problem 79
2 Determining Characteristics Surfaces in Time-Dependent Three-Dimensional Flows 82
3 Results of the Numerical Analysis 86
Acknowledgments 87
References 88

EXPLICIT ALGEBRAIC REYNOLDS STRESS MODELS FOR ANISOTROPIC WALL-BOUNDED FLOWS
F. R. Menter, A. V. Garbaruk, and Y. Egorov 89
1 Introduction 89
2 Model Formulation 91
3 Flow Solver 95
4 Test Cases 95
5 Summary 102
Acknowledgments 103
References 103

Chapter Two Shock Interaction 105

CHAPTER SUMMARY 106

LOW AND HIGH ENTHALPY SHOCK WAVE / BOUNDARY LAYER INTERACTIONS AROUND CYLINDER-FLARE MODELS
B. Chanetz 107
1 Introduction 107
2 Low Enthalpy Laminar Interaction 108
3 Low Enthalpy Transitional Interaction 111
4 Low Enthalpy Turbulent Interaction 114
5 High Enthalpy Interaction 115
6 Concluding Remarks 117
References 118

NUMERICAL PREDICTION OF THREE-DIMENSIONAL SHOCK-INDUCED TURBULENT FLOW SEPARATION SURROUNDING BODIES OF REVOLUTION ADJACENT TO A FLAT SURFACE
A. D. Grosvenor, A. A. Zheltovodov, and E. K. Derunov 119
1 Introduction 119
2 Experimental Test Conditions 121
3 Numerical Scheme 122
4 Numerical Model 122
5 Discussion of Predictions and Comparison of Measurements with Computational Fluid Dynamics . 124
6 Shock Capturing Options 136
7 Concluding Remarks 139
Acknowledgments 139
References 139

EFFECT ON A SHOCK WAVE BOUNDARY LAYER INTERACTION OF AIR JET VORTEX GENERATORS
L. J. Souverein and J.-F. Debiève 141
1 Introduction 141
2 Experimental Arrangement and Flow Conditions 142
3 Modification of the Upstream Boundary Layer by Air Injection 145
4 Modification of Separation 149
5 Modification of the Shock Dynamics 152
6 Results of Recapitulation 153
7 Concluding Remarks 155
Acknowledgments 155
References 155

NUMERICAL STUDY OF THREE-DIMENSIONAL MODULATIONS IN A SHOCK-INDUCED SEPARATION
L. Agostini, L. Larchevêque, E. Garnier, and E. De Martel . 157
1 Introduction 157
2 Numerical Method and Computational Setup 158
3 Validation 159
4 Results 165
5 Concluding Remarks and Future Works 167
Acknowledgments 168
References 168

NUMERICAL SIMULATION OF SHOCK-INDUCED SEPARATED FLOWS IN OVEREXPANDED ROCKET NOZZLES
A. Shams, S. Girard, and P. Comte 169
1 Introduction 170
2 Phenomenology of Separated Flows 172
3 Description of the Computations 173
4 Formation of the Cap-Shock Pattern 176
5 Evolution of the Restricted Shock Separation Regime 181
6 Concluding Remarks 188
Acknowledgments 189
References 189

Chapter Three High Enthalpy Flows 191
CHAPTER SUMMARY 192

DEVELOPMENT OF A COMPACT ELECTRON BEAM FLUORESCENCE INSTRUMENT FOR HIGH ENTHALPY FLOW CHARACTERIZATION
B. Diop, A. Mohamed, and J. Bonnet 193
1 Introduction 193
2 Prototype for In-Flight Measurements 196
3 Laboratory Prototype 198
4 Experimental Details and Results 199
5 Concluding Remarks 203
Acknowledgments 204
References 204

ACTIVE CONTROL OF HYPERSONIC SHOCK LAYER DISTURBANCES
T. V. Poplavskaya and A. A. Maslov 205
1 Introduction 205
2 Numerical Formulation of the Problem 206
3 Experimental Equipment and Diagnostic Method 207
4 Results 208
5 Concluding Remarks 214
Acknowledgments 215
References 215

EVALUATION OF NONEQUILIBRIUM BOUNDARY CONDITIONS FOR HYPERSONIC RAREFIED GAS FLOWS
N. T. P. Le, Ch. J. Greenshields, and J. M. Reese 217
1 Introduction 217
2 Review of Nonequilibrium Boundary Conditions 219

3 Numerical Implementation and Simulation Results 221
4 Results 224
5 Concluding Remarks 229
Acknowledgments 229
References 229

EXPERIMENTAL STUDY AND NUMERICAL MODELING OF VIBRATIONAL OXYGEN TEMPERATURE PROFILES BEHIND A STRONG SHOCK WAVE FRONT
I. E. Zabelinskii, L. B. Ibraguimova, O. P. Shatalov, and Yu. V. Tunik 231
1 Introduction 231
2 Determination of the Vibrational Oxygen Temperature . . . 233
3 Time Histories of the Vibrational Temperature 236
4 Preliminary Results of the Simulation and Comparison with the Experiment 238
5 Concluding Remarks 241
Acknowledgments 242
References 242

HYPERSONIC LAMINAR/TURBULENT TRANSITION: COMPUTATIONS AND EXPERIMENTS
E. Orlik, V. Kornilov, M. Ferrier, I. Fedioun, and D. Davidenko 243
1 Introduction 243
2 Flat Plate Experiments and Associated $\boldsymbol{N}$ Factors 244
3 Transition on the Forebody in T-313: Numerical Prediction 247
4 Concluding Remarks and Perspectives 249
References 252

DEPENDENCE AND SENSITIVITY ON THE AEROTHERMOCHEMICAL MODEL OF ATMOSPHERIC REENTRY TRAJECTORIES
A. Viviani, L. Savino, and G. Pezzella 253
1 Introduction 253
2 Preliminary Capsule Reentry Scenario 255
3 Reentry Trajectory Dispersion 256
4 Computational Analysis 258
5 Reaction Mechanisms 258
6 Numerical Results 260

7 Analysis of the Capsule Reentry Trajectory Dispersion . . . 262
8 Concluding Remarks . . . 264
References . . . 266

CHEMICAL NONEQUILIBRIUM EFFECTS IN THE WAKE OF AN OBSTACLE IN HYPERSONIC BOUNDARY-LAYER FLOWS
M. Birrer and C. Stemmer . . . 267
1 Introduction . . . 267
2 Numerical Details . . . 268
3 Simulations . . . 269
4 Results . . . 271
5 Concluding Remarks . . . 273
Acknowledgments . . . 276
References . . . 276

AEROTHERMODYNAMICS OF EXPERT BALLISTIC VEHICLE AT HYPERSONIC SPEEDS
A. M. Kharitonov, N. P. Adamov, V. F. Chirkashenko, I. I. Mazhul, S. I. Shpak, A. N. Shiplyuk, L. G. Vasenyov, V. I. Zvegintsev, and J. M. Muylaert . . . 277
1 Introduction . . . 277
2 Experimental Conditions . . . 278
3 Total Aerodynamic Characteristics . . . 280
4 Boundary Layer Transition . . . 284
5 Pressure Distribution over the Surface . . . 286
6 Distribution of Heat Fluxes on the Surface . . . 290
7 Concluding Remarks . . . 292
References . . . 293

EXPERIMENTS ON HYPERSONIC BOUNDARY LAYER TRANSITION ON BLUNT CONES WITH ACOUSTIC-ABSORPTION COATING
A. Shiplyuk, S. Lukashevich, D. Bountin, A. Maslov, and H. Knaus . . . 295
Nomenclature . . . 295
1 Introduction . . . 296
2 Model . . . 297
3 Experimental Results . . . 298
4 Concluding Remarks . . . 303
References . . . 303

Chapter Four Heat Transfer 305

CHAPTER SUMMARY 306

LAMINAR–TURBULENT FLOW AROUND A WEDGE PLACED ON SHARP AND BLUNTED PLATES
V. Borovoy, V. Mosharov, V. Radchenko, and A. Noev 307

1 Introduction 307
2 Model and Flow Characteristics 308
3 Measurement Methods 310
4 Investigation of Heat Transfer and Flow Structure 313
5 Concluding Remarks 319
Acknowledgments 319
References 319

THE TANGENTIAL GAS INJECTION AS THE MEANS OF HEAT PROTECTION OF A BLUNT BODY STREAMLINED BY DUSTED GAS
E. B. Vasilevskiy and L. V. Yakovleva 321

Nonstandard Nomenclature 321
1 Introduction 322
2 Model 323
3 Supply System of the Injected Gas into the Model 325
4 Creating of Dusted Flow in the Wind Tunnel 326
5 Particles 329
6 Experimental Results 331
7 Concluding Remarks 333
Acknowledgments 333
References 333

EXPERIMENTAL STUDIES OF PRE-X VEHICLE HEAT TRANSFER IN PGU-7 TEST FACILITY
R. V. Kovalev, V. V. Kislykh, A. E. Kolozezniy, V. V. Kudryavtsev, V. P. Marinin, V. I. Vlasov, and B. A. Zemliansky 335

1 Introduction 335
2 Experimental Tools 337
3 Measurement Technique 341
4 Experimental Results 343
5 Concluding Remarks 349
Acknowledgments 349
References 349

SIMULATION OF OXYGEN ATOM HETEROGENEOUS RECOMBINATION ON Al_2O_3 FROM *AB INITIO* APPROACH
V. L. Kovalev, A. A. Kroupnov, M. Ju. Pogosbekian, and L. P. Sukhanov 351
1 Introduction 351
2 Quasi-Classical Trajectory Methodology 353
3 Potential Energy Surface Calculation Methodology 356
4 Results and Discussions 358
Acknowledgments 363
References 363

THE METHOLOGY FOR DETERMINATION OF CATALYTIC PROPERTIES OF SiC SAMPLES FOR SPECIFIED PRE-X AND MSRO CONDITIONS
V. I. Sakharov, A. F. Kolesnikov, A. N. Gordeev, and J.-L. Vérant 365
1 Introduction 365
2 Numerical Modeling 367
3 PRE-X Duplicated Air Conditions 369
4 Mars Sample Return Orbiter Duplicated CO_2 Conditions . . 375
5 Concluding Remarks 378
Acknowledgments 379
References 379

NAVIER–STOKES ANALYSIS OF SCALE EFFECTS ON ABLATION IN CARBON–CARBON ROCKET NOZZLES
D. Bianchi, F. Nasuti, E. Martelli, and M. Onofri 381
1 Introduction 381
2 Theoretical Model 383
3 Numerical Procedure 384
4 Results 385
5 Concluding Remarks 392
Acknowledgments 393
References 393

PECULIARITIES OF FLOW AND HEAT TRANSFER IN THE BASE REGION OF GENERIC MODEL OF MARTIAN DESCENT VEHICLE
V. Ya. Borovoy, I. V. Egorov, D. V. Ivanov, and A. S. Skuratov . 395
1 Introduction 395
2 Experimental Technique 396
3 Numerical Simulation 397

4 Results and Discussion 398
Acknowledgments 402
References 402

Chapter Five Aeroacoustics 403

CHAPTER SUMMARY 404

ACOUSTIC ENVIRONMENT RESULTING IN INTERACTION OF LAUNCH VEHICLE MAIN ENGINES JETS WITH A LAUNCH PAD HAVING CLOSED LONG DUCTS LIKE A TUNNEL
V. V. Kudryavtsev and A. V. Safronov 405

1 Introduction 405
2 Problem Statement 407
3 Acoustic Model of Jet Interaction with Closed Long Duct 408
4 Multinozzle and Multiduct Configurations 414
5 Results of Calculations and Their Validation 416
6 Concluding Remarks 418
Acknowledgments 419
References 419

REYNOLDS NUMBER EFFECT IN A PROBLEM OF SOUND GENERATION BY ROUND AND TRUNCATED CYLINDER STREAMLINED BY TURBULENT FLOW
V. Kopiev, M. Zaitsev, and N. Ostrikov 421

1 Introduction 421
2 Results 422
3 Concluding Remarks 427
References 428

DEVELOPMENT OF A FREE ROUND JET AT DIFFERENT CONDITIONS AT THE NOZZLE EXIT UNDER AN ACOUSTIC ACTION
Yu. A. Litvinenko, G. R. Grek, G. V. Kozlov, A. M. Sorokin, and M. V. Litvinenko 429

1 Introduction 429
2 Experimental Setup and Measurement Procedure 431
3 Measurement and Visualization Data 434
4 Discussion 443

5 Concluding Remarks 446
Acknowledgments 447
References 447

Chapter Six Flow Control 449

CHAPTER SUMMARY 450

CONVECTIVE INSTABILITIES IN A BACKWARD-FACING STEP FLOW: GLOBAL FORCED PERTURBATIONS
O. Marquet and D. Sipp 451
1 Introduction 451
2 Noise Amplification and Frequency Selection 452
3 Linear Frequency Approach 455
References 459

ADJOINT-BASED CONTROL OF AFTERBODY FLOW UNSTEADINESS IN THE COMPRESSIBLE REGIME
Ph. Meliga, D. Sipp, and J.-M. Chomaz 461
1 Introduction 461
2 Theoretical Framework 462
3 Results 466
4 Concluding Remarks and Perspectives 469
References 470

MODEL REDUCTION AND CONTROL OF A SEPARATING BOUNDARY-LAYER FLOW
U. Ehrenstein, P.-Y. Passaggia, and F. Gallaire 471
1 Introduction 471
2 Flow Configuration and Numerical Model 472
3 Bi-Orthogonal and Least-Square Projection 476
4 Control Results 479
5 Concluding Remarks 481
References 481

ASYMPTOTICAL MODELS OF BOUNDARY LAYER FLOW CONTROL
I. I. Lipatov 483
1 Local Surface Heating 483
2 Flows Near Porous Walls 487
References 489

GLOBAL STABILITY ANALYSIS — A KEY ENABLER IN REDUCED ORDER MODELS AND FLOW CONTROL
M. Morzyński, W. Stankiewicz, F. Thiele, B. R. Noack, and G. Tadmor 491
1 Introduction 491
2 Empirical Galerkin Model 492
3 Global Flow Stability Eigenmodes 493
4 Improvements of the Galerkin Model 494
5 Least-Order Galerkin Model of NACA-0012 Airfoil Flow . 497
6 Concluding Remarks 499
Acknowledgments 501
References 501

REDUCED ORDER MODELS FOR CLOSED LOOP CONTROL: COMPARISON BETWEEN POD, BPOD, AND GLOBAL MODES
A. Barbagallo, D. Sipp, and P. J. Schmid 503
1 Introduction 503
2 Configuration and Mathematical Modeling 504
3 Model Reduction 505
4 Input–Output Behavior of the Stable Subspace 508
5 Linear Quadratic Gaussian Control and Comparison 510
6 Concluding Remarks 512
References 512

INVESTIGATION OF CROSS FLOW FORCES INFLUENCE ON INCOMPRESSIBLE LAMINAR FLOW
M. N. Kogan and A. A. Basalaev 513
1 Problem Definition 513
2 Flow Under the Action of Cross Forces in a Linear Approximation 514
3 Vertical Forces in a Duct 514
4 Flow in a Duct Under Action of Three-Dimensional Cross Forces 516
5 Concluding Remarks 518
Acknowledgments 520

NUMERICAL MODELING OF SEPARATED FLOWS IN THREE-DIMENSIONAL DIFFUSERS AND APPLICATION OF SYNTHETIC JETS FOR SEPARATION CONTROL
S. Yu. Krasheninnikov, D. E. Pudovikov, and S. A. Torohov . 521
1 Design Flow Study in an Annular Duct by the RANS/URANS Methods 522

2 Application of Synthetic Jets for Separated Flow Control 524
3 Concluding Remarks 528
Acknowledgments 528
References 528

EXPERIMENTAL AND NUMERICAL STUDIES OF NONEQUILIBRIUM EFFECTS IN FRAMEWORK OF MAGNETOHYDRODYNAMIC PARACHUTE CONCEPT
V. A. Bityurin, A. N. Bocharov, N. A. Popov, and D. S. Baranov 529
1 Introduction 529
2 Problem Setup 531
3 Governing Equations 533
4 Chemical Kinetics Model 535
5 Initial and Boundary Conditions 536
6 Computational Details 536
7 Results 536
8 Experimental Test on the Nonequilibrium Ionization Due to Magnetic Field 540
9 Concluding Remarks 542
Acknowledgments 543
References 543

STUDY OF THE INCIPIENT SPOT BREAKDOWN CONTROLLED BY RIBLETS
V. G. Chernoray, G. R. Grek, V. V. Kozlov, and Yu. A. Litvinenko 545
1 Introduction 545
2 Experimental Setup and Measurement Procedure 547
3 Results of Measurements 549
4 Concluding Remarks 555
Acknowledgments 555
References 555

FLOW CONTROL IN A SUPERSONIC INLET MODEL BY ELECTRICAL DISCHARGE
S. Leonov, D. Yarantsev, and F. Falempin 557
1 Introduction 557
2 Experimental Approach 558
3 Discharge Parameters 561

4 Experimental Results 562
5 The First Shock Angle and Position Versus Plasma Power . 565
6 Concluding Remarks 566
Acknowledgments 567
References 567

Author Index **569**

Color Plates **I**