## Contents

**List of Figures**
- [viii](#)

**List of Tables**
- [xix](#)

**Preface**
- [xxi](#)

**Acknowledgments**
- [xxiii](#)

**List of Abbreviations**
- [xxv](#)

**Nomenclature**
- [xxviii](#)

1. **Introduction to Aircraft Aerodynamic Design**
   - 1.1 Introduction [1](#)
   - 1.2 Advanced Wing Design: Cycle 2 [20](#)
   - 1.3 Integrated Aircraft Design and MDO [29](#)
   - 1.4 Aerodynamic Design and CFD [35](#)
   - 1.5 Learn More by Computing [42](#)
   - References [43](#)

2. **Airflow Physics and Mathematical Models**
   - 2.1 Introduction to Wing Flow Physics [45](#)
   - 2.2 Shape Determines Performance [46](#)
   - 2.3 Boundary-Layer Development [51](#)
   - 2.4 Physics of Wing-Lift Creation [55](#)
   - 2.5 Behavior and Interaction of Flow Phenomena [63](#)
   - 2.6 Drag Taxonomy [69](#)
   - 2.7 Example: Swept-Wing Flow Physics [76](#)
   - 2.8 Physics Models: The Equations [80](#)
   - 2.9 Averaging for Turbulent Flows [85](#)
   - 2.10 Learn More by Computing [97](#)
   - References [97](#)

3. **Concepts and Computational Models in Wing Design**
   - 3.1 Introduction: Mapping Planform to Lift and Drag [100](#)
   - 3.2 Computational VLMs [101](#)
   - 3.3 Planform Design Studies with VLM [106](#)
   - 3.4 Wings for High Speed [117](#)
   - 3.5 Learn More by Computing [125](#)
   - References [135](#)
## Table of Contents

### 4 Finite-Volume Schemes for the Euler Equations

4.1 Introduction to Computing Flow with Shock Waves 137
4.2 Finite-Volume Methodology 153
4.3 Time Integration Schemes 165
4.4 CFD Workflow for Nozzle Problems 169
4.5 Learn More by Computing 177
References 177

### 5 Airframe Computer-Aided Design and Automated Grid Generation

5.1 Introduction and Overview 180
5.2 Curve and Surface Geometry Representation 182
5.3 Airfoils and Surfaces 187
5.4 Grid Generation 195
5.5 SUMO Mesh Generation 202
5.6 Euler Volume Grids by TetGen 207
5.7 Learn More by Computing 210
References 211

### 6 Computational Fluid Dynamics for Steady and Unsteady Flows

6.1 Introduction: Scope and Objectives 213
6.2 RANS Software 214
6.3 RANS Finite-Volume Numerical Modeling 219
6.4 Due Diligence CFD 227
6.5 Nonlinear Aerodynamics of Increasing $M_{\infty}$ 230
6.6 Time-Accurate Simulations 235
6.7 Hybrid RANS–LES for Unsteady Flow 236
6.8 Steady and Unsteady Separated Flows 239
6.9 Learn More by Computing 244
References 244

### 7 Fast Computation of Airfoil Flow

7.1 Introduction 248
7.2 Zonal Approach: Physical Observations 248
7.3 Mses: Fast Airfoil Analysis and Design System 251
7.4 Outer Euler Flow Solver 251
7.5 Boundary-Layer and Integral Boundary-Layer Models 256
7.6 Drag Calculation 261
7.7 Newton Solution Method 264
7.8 Airfoil Computations 265
7.9 Mses Design Application 267
7.10 Learn More by Computing 270
References 270
# Contents

8 **Airfoil Design Considerations**

- 8.1 Introduction to Airfoil Design
- 8.2 Subcritical-Speed Airfoils $M_\infty \leq 0.7$
- 8.3 Transonic Airfoils $0.7 < M_\infty \leq 0.9$
- 8.4 Supersonic-Speed Airfoils $0.9 < M_\infty \leq 2$
- 8.5 Multielement Airfoils for High Lift
- 8.6 Optimization Example: ADODG Test Case RAE2822
- 8.7 Learn More by Computing

References 299

9 **Wing Design Considerations**

- 9.1 Introduction to Aerodynamic Wing Design
- 9.2 Subsonic Straight-Wing Design
- 9.3 Transonic Swept-Wing Design
- 9.4 Supersonic Slender-Wing Design
- 9.5 Further Configuration Development
- 9.6 Wing–Body Mathematical Shape Optimization
- 9.7 Learn More by Computing

References 349

10 **Configuration Development and Flying Qualities**

- 10.1 Introduction
- 10.2 Stability of Aircraft Motion
- 10.3 Flight Simulation for Design Assessment
- 10.4 Building Aerodynamic Tables
- 10.5 Applications: Configuration Design and Flying Qualities
- 10.6 Learn More by Computing

References 396

11 **Airload–Structure Interactions and Aero-Elastic Effects**

- 11.1 Introduction
- 11.2 Model of Wing Section in Torsion
- 11.3 Aero-Elastic Configuration Model
- 11.4 Modular Framework for Aero-Elastic Loop
- 11.5 Case Studies: Elasto-static Wing Effects
- 11.6 Learn More by Computing

References 424

Index 426