## Contents

**Preface**

<table>
<thead>
<tr>
<th>Preface</th>
<th>page xi</th>
</tr>
</thead>
</table>

### 1 Introduction

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 History and Outlook</td>
<td>2</td>
</tr>
<tr>
<td>1.2 Dimensionless Groups</td>
<td>5</td>
</tr>
<tr>
<td>1.3 Mass and Momentum Balance Equations</td>
<td>7</td>
</tr>
<tr>
<td>1.4 Inviscid and Viscous Newtonian Fluids: The Incompressible Euler and Navier–Stokes Equations</td>
<td>9</td>
</tr>
<tr>
<td>1.5 Impact at Liquid Surface and Equations of Impulsive Motion</td>
<td>12</td>
</tr>
<tr>
<td>1.6 Boundary Layer Equations</td>
<td>13</td>
</tr>
<tr>
<td>1.7 Quasi-one-dimensional and Lubrication Approximations in Problems on Drop Impact and Spreading</td>
<td>15</td>
</tr>
<tr>
<td>1.8 Wettability</td>
<td>19</td>
</tr>
<tr>
<td>1.9 Rheological Constitutive Equations of Non-Newtonian Fluids and Solids</td>
<td>22</td>
</tr>
<tr>
<td>1.10 Instabilities and Small Perturbations: Rayleigh Capillary Instability, Bending Instability, Kelvin–Helmholtz Instability, Rayleigh–Taylor Instability</td>
<td>29</td>
</tr>
<tr>
<td>1.11 Total Mechanical Energy of Deforming Bodies: Where Is It Lost?</td>
<td>37</td>
</tr>
<tr>
<td>1.12 References</td>
<td>39</td>
</tr>
</tbody>
</table>

### 2 Selected Basic Flows and Forces

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Inviscid Flow in a Thin Film on a Wall</td>
<td>44</td>
</tr>
<tr>
<td>2.2 Propagation of Kinematic Discontinuity</td>
<td>52</td>
</tr>
<tr>
<td>2.3 External Irrotational Flows About Blunt Bodies</td>
<td>58</td>
</tr>
<tr>
<td>2.4 Flows Past Arbitrary Axisymmetric Bodies of Revolution</td>
<td>61</td>
</tr>
<tr>
<td>2.5 Transient Motion in Inviscid Fluids and Forces Associated with the Added Masses</td>
<td>63</td>
</tr>
<tr>
<td>2.6 Friction and Shape Drag</td>
<td>70</td>
</tr>
<tr>
<td>2.7 Dynamics of a Rim Bounding a Free Liquid Sheet</td>
<td>75</td>
</tr>
<tr>
<td>2.8 References</td>
<td>82</td>
</tr>
</tbody>
</table>
# Contents

## Part I Collision of Liquid Jets and Drops with a Dry Solid Wall

### 3 Jet Impact onto a Solid Wall

- 3.1 Normal and Inclined Impact of Inviscid Planar Jets onto a Plane Wall 87
- 3.2 Normal Impact of Axisymmetric Impinging Jet 91
- 3.3 Hydraulic Jump 96
- 3.4 References 98

### 4 Drop Impact onto a Dry Solid Wall

- 4.1 Inviscid Flow on a Wall Generated by Inertia-Dominated Drop Impact 102
- 4.2 Flow in a Spreading Viscous Drop, Including Description of Inclined Impact and Thermal Effects 106
- 4.3 Initial Phase of Drop Impact 120
- 4.4 Maximum Spreading Diameter 123
- 4.5 Time Evolution of the Drop Diameter: Rim Dynamics on a Wall 126
- 4.6 Drop Impact onto Spherical Targets and Encapsulation 128
- 4.7 Outcomes of Drop Impact onto a Dry Wall 130
- 4.8 The Effect of Reduced Pressure of the Surrounding Gas 133
- 4.9 Drop Impact onto Hot Rigid Surfaces 134
- 4.10 Drop Impact with Solidification and Icing 140
- 4.11 References 149

### 5 Drop Impact onto Dry Surfaces with Complex Morphology

- 5.1 Drop Splashing on Rough and Textured Surfaces 156
- 5.2 Drop Impact Close to a Pore 159
- 5.3 Drop Impact onto Porous Surfaces 165
- 5.4 Nano-textured Surfaces: Drop Impact onto Suspended Nanofiber Membranes 177
- 5.5 Drop Impact onto Nanofiber Mats on Impermeable Substrates and Suppression of Splashing 186
- 5.6 Hydrodynamic Focusing in Drop Impact onto Nanofiber Mats and Membranes 189
- 5.7 Impact of Aqueous Suspension Drops onto Non-Wettable Porous Membranes: Hydrodynamic Focusing and Penetration of Nanoparticles 200
- 5.8 Drop Impact onto Hot Surfaces Coated by Nanofiber Mats 214
- 5.9 Nano-textured Surfaces: Suppression of the Leidenfrost Effect 223
- 5.10 Bouncing Prevention: Dynamic Electrowetting 231
- 5.11 References 247
## Part II Drop Impacts onto Liquid Surfaces

6 Drop Impacts with Liquid Pools and Layers

6.1 Drop Impact onto Thin Liquid Layer on a Wall: Weak Impacts and Self-similar Capillary Waves

6.2 Strong Impacts of Drops onto Thin Liquid Layer: Crown Formation

6.3 Drop Impact onto Thick Liquid Layers on a Wall: Cavity Expansion

6.4 Residual Film Thickness

6.5 Drop Impact onto a Deep Liquid Pool: Crater and Crown Formation, the Worthington Jets and Bubble Entrapment

6.6 Bending Instability of a Free Viscous Rim on Top of the Crown: Mechanism of Splash

6.7 Impact of Drop Train

6.8 References

## Part III Spray Formation and Impact onto Surfaces

7 Drop and Spray Diagnostics

7.1 Fundamentals

7.2 Non-Optical Measurement Techniques

7.3 Direct Imaging

7.4 Non-Imaging Optical Measurement Techniques

7.5 Measurement Techniques for Liquid Films

7.6 References

8 Atomization and Spray Formation

8.1 Primary Atomization

8.2 Secondary Aerodynamic Breakup

8.3 Drop–Drop Binary Collisions in Sprays

8.4 Secondary Drop Detachment from a Filament

8.5 Secondary Electrically Driven Drop Breakup: The Rayleigh Limit

8.6 References

9 Spray Impact

9.1 Spray Impact onto Liquid Films

9.2 Description of the Secondary Spray

9.3 Correlations for Spray Impact Phenomena

9.4 References
## Part IV  Collisions of Solid Bodies with Liquid

### 10 Rigid Body Collision with Liquid Surface

10.1 Impact of Rigid Body at Liquid Surface 473
10.2 Rigid Body Entry and Penetration into Liquid: The Wagner Problem 478
10.3 Rigid Sphere Entry and Penetration into Liquid 482
10.4 References 485

### 11 Particle Impact onto Wetted Wall

11.1 Motion of a Rigid Immersed Particle near a Wall 487
11.2 Deformation of an Immersed Elastic Particle 489
11.3 Restitution Coefficient 491
11.4 Effect of Particle Material and Surface Properties 493
11.5 References 495

## Part V  Solid–Solid Collisions

### 12 Particle and Long Bar Impact onto a Rigid Wall

12.2 Impingement of a Rigid/Semi-Brittle Ice Particle 506
12.3 References 513

### 13 Shaped-charge (Munroe) Jets and Projectile Penetration

13.1 Shaped-charge Jet Penetration Depth 515
13.2 Crater Configuration due to Shaped-charge Jet Penetration 517
13.3 Normal Penetration of an Eroding Projectile into an Elastic–Plastic Target 521
13.4 High-Speed Penetration 542
13.5 Quasi-Steady Penetration of an Eroding Projectile 544
13.6 Normal and Oblique Penetration of a Rigid Projectile into an Elastic–Plastic Target 545
13.7 Explosion Welding 553
13.8 References 564

### 14 Fragmentation

14.1 Ice Particle Collision with a Dry Solid Wall 566
14.2 Ice Particle: Fragmentation Threshold for an Impact Velocity 570
14.3 Dynamic Fracture of a Deforming Elastic–Plastic Material 573
Contents

14.4 Fragmentation of Thick Elastic–Plastic Targets 577
14.5 Fragmentation of an Impacting Projectile 587
14.6 Debris Cloud Produced by Projectile Impact, Vulnerability 590
14.7 Effect of the Energy of the Plastic Dissipation on the Size of the Smallest Fragment 598
14.8 References 599

Index 604