

# Contents

<b>Notation</b> .....	XV
<b>1. Introduction</b> .....	1
1.1 Space Missions .....	1
1.2 Interdisciplinary Stimuli .....	6
1.3 Problems of Fluid Physics .....	9
1.4 Zero Mass Acceleration or Weightlessness .....	13
1.5 Flight Selection and Simulation .....	15
References .....	18
<b>2. Interface Tension and Contact Angle</b> .....	21
2.1 Molecular Attraction and Condensation .....	21
2.2 The Interface Tension .....	24
2.2.1 Theoretical Aspects .....	24
2.2.2 Experimental Methods .....	25
2.2.3 Qualitative Rules for the Interface Energy .....	27
2.3 The Static Contact Angle .....	30
2.4 The Dynamic Contact Angle .....	31
2.5 Merging of Drops and Bubbles .....	35
2.6 Adhesion Forces in Liquid Films .....	37
References .....	38
<b>3. Capillary Shape and Stability</b> .....	41
3.1 Balance of Forces .....	41
3.2 Minimization of Energy .....	44
3.3 Analytical Solutions of the Capillary Equation .....	47
3.3.1 Rise of Liquid in a Tube .....	47
3.3.2 Spherical Surfaces .....	49
3.3.3 Rise of a Liquid in Contact with an Infinite Plane ..	51
3.4 Axisymmetric Surfaces .....	52
3.5 Container Shape and Wetting .....	57
3.6 Drops at Low Bond Numbers .....	59

3.7	Representations of the Capillary Equation .....	61
3.7.1	Cartesian Coordinates $z(x, y)$ .....	62
3.7.2	Polar Coordinates $r(\vartheta, \varphi)$ .....	62
3.7.3	Cylindrical Coordinates $r(\varphi, z)$ .....	63
3.7.4	Cylindrical Coordinates $z(r, \varphi)$ .....	63
3.7.5	Axisymmetry .....	64
	References .....	65
<b>4.</b>	<b>Stability Criteria .....</b>	<b>67</b>
4.1	Stability of Capillary Surfaces .....	67
4.2	Breakage of Cylindrical Surfaces .....	69
4.3	Second Variation of Energy .....	73
4.4	Normal Deformations of Liquid Zones .....	75
4.4.1	Instabilities of Periodic Surfaces .....	75
4.4.2	Normal Deformations of a Circular Cylinder .....	76
4.4.3	The Symmetric Instability of the Catenoid .....	77
4.5	Nonaxisymmetric Instabilities .....	79
4.5.1	Lateral Deformations of the Center Line .....	79
4.5.2	Liquid Rings .....	81
4.6	The Minimum-Volume Condition .....	83
4.7	Linear Stability Analysis .....	85
	References .....	87
<b>5.</b>	<b>Axisymmetric Liquid Columns at Rest and Under Rotation</b> .....	<b>89</b>
5.1	Introduction .....	89
5.2	The Normal Deformations .....	90
5.2.1	The Symmetric Mode $D\{2, 0\}$ .....	92
5.2.2	The Antimetric Mode $D\{1, 0\}$ .....	94
5.2.3	The Lateral Instability $D\{0, 1\}$ .....	96
5.2.4	Stability of a Liquid Ring .....	98
5.3	Nearly Cylindrical Surfaces .....	101
5.3.1	Fourier Expansion of an Axisymmetric Surface ....	101
5.3.2	The Symmetric Instability $D\{2, 0\}$ .....	102
5.3.3	The Antimetric Instability $D\{1, 0\}$ .....	102
5.3.4	The Lateral Mode $D\{0, 1\}$ .....	103
5.3.5	Nonzero Bond Number .....	104
5.4	Rotating Free Drops .....	106
5.4.1	Motivation .....	106
5.4.2	Shape of Rotating Drops .....	107
5.4.3	Stability .....	110
5.4.4	Conservation of Angular Momentum .....	113
5.4.5	Finite-Element Analysis .....	114
	References .....	117

<b>6. Liquid Zones</b>	119
6.1 Liquid Bridges Between Parallel Plates	119
6.1.1 Introduction	119
6.1.2 Branches of Solutions of the Capillary Equation	120
6.1.3 Properties of the Inflection Point	123
6.1.4 The Instability Due to the Bifurcation (Due to $D\{1, 0\}$ )	125
6.1.5 The Instability Due to the Minimum Volume (Due to $D\{2, 0\}$ )	127
6.1.6 Differing Contact Angles	129
6.1.7 Gravity	129
6.1.8 Key Points	134
6.2 Double Float Zones	135
6.2.1 Introduction	135
6.2.2 Unduloids and Nodoids	137
6.2.3 Branches of Solutions	138
6.2.4 Results of the Spacelab Experiments	141
6.2.5 The Stability Diagram	143
6.2.6 Key Points	145
References	147
<b>7. Canthotaxis/Wetting Barriers/Pinning Lines</b>	149
7.1 Introduction	149
7.2 Straight Wetting Barriers	151
7.2.1 The Wetting Tile	151
7.2.2 The Wetting Stripe	153
7.2.3 The Wetting Cross	154
7.2.4 Circular Tubes	155
7.2.5 Large Liquid Volumes	157
7.3 Liquid Surfaces in Wedges	158
7.4 Taylor Expansions at Small Radii	162
7.4.1 Alternative Winding Functions	162
7.5 Liquid Surfaces in Square Cylinders, $\cos \gamma_1 + \cos \gamma_2 = 0$	164
7.6 Towards Modeling Canthotaxis	169
7.6.1 Helicoid and Catenoid	169
7.6.2 Winding Rates $[\partial z(\varphi)/\partial \varphi]_{r=0} \propto [\cos(s\varphi)]^k$	170
7.6.3 Winding Rate of Infinity	171
7.6.4 Circular Tube with Complementary Contact Angles	172
References	177
<b>8. Cylindrical Containers</b>	179
8.1 Introduction	179
8.1.1 Fields of Application	179
8.1.2 Liquids in Edges	180

8.2	The Integral Theorem for Cylindrical Vessels .....	182
8.2.1	Application of Divergence Theorem .....	182
8.2.2	Minimization of Energy with Respect to Height ....	183
8.2.3	Evaluation of Wedge Contributions .....	185
8.3	Examples .....	186
8.3.1	Ice Cream Cone .....	186
8.3.2	Rhombic Cylinder .....	188
8.3.3	Regular Polygon .....	190
8.3.4	Liquid in a Rotating Wedge .....	192
8.3.5	No Wetting of Wedge .....	193
8.3.6	Liquid Volume Pressed into a Wedge .....	195
8.4	Stability of Convex Cylindrical Surfaces .....	199
8.4.1	Longitudinal Normal Deformations .....	199
8.4.2	Axially Periodic Meniscus Shapes .....	200
8.4.3	Adjustment to Fit Solid Edges .....	201
8.4.4	Volume and Energy .....	203
8.4.5	Rotating Wedges .....	205
8.5	The MAXUS Experiment DYLCO .....	205
	References .....	211
<b>9.</b>	<b>Liquid Surfaces in Polyhedral Containers .....</b>	<b>213</b>
9.1	Spherical Surfaces at Edges and Corners .....	213
9.1.1	Nonwetting Drops .....	213
9.1.2	Drops in Planar Wedges .....	214
9.1.3	Drops in Spherical Wedges .....	216
9.1.4	Liquid Drops in a Tripod .....	217
9.1.5	Regular $N$ -Pods .....	217
9.2	Transition Between the Corner and the Wedge .....	222
9.2.1	Liquid Volumes in Polyhedra .....	222
9.2.2	Exponential Piling-Up in Corners .....	223
9.2.3	Numerical Calculation of Corner Volume .....	225
9.2.4	Similarity of Corner Volumes .....	228
9.2.5	Finite Wedge Length .....	229
9.2.6	Accuracy of the Present Approach .....	231
9.2.7	Prospects .....	232
	References .....	233
<b>10.</b>	<b>Playing with Stability .....</b>	<b>235</b>
10.1	Proboscides .....	235
10.1.1	Finite Rhombic Prisms .....	235
10.1.2	Canonical Proboscides .....	238
10.1.3	Interface Configuration Experiment .....	241
10.2	Exotic Containers .....	246
10.2.1	Circular Tubes with Unusual Properties .....	246
10.2.2	Adjustment of Container Shape .....	249
10.2.3	Integration of Container Shape .....	251

10.2.4	Mismatch of Volume and/or Contact Angle	253
10.2.5	Residual Gravity	254
10.2.6	Drop Tower Tests	256
	References	258
<b>11.</b>	<b>Liquid Penetration into Tubes and Wedges</b>	<b>259</b>
11.1	About the Momentum, or Navier–Stokes, Equation	259
11.2	Penetration into Capillaries	261
11.2.1	Cylindrical Vessels	261
11.2.2	Liquid Rise in Capillaries	263
11.2.3	Liquid Penetration into Wedges	264
11.2.4	Similarity Solutions for Long Times	266
11.2.5	Numerical Solution	269
11.3	Dynamics of Liquids in Edges and Corners	272
11.3.1	The DYLCO Experimental Module	272
11.3.2	Drop Towers Tests for DYLCO	273
11.3.3	Conduct of the IML-2 Experiment	274
11.3.4	Results of the DYLCO IML-2 Experiment	276
11.4	The Geometric Friction Coefficient $\Phi$	278
11.4.1	Flow in Rectangular Tubes	278
11.4.2	Flow in Parallelograms	283
	References	285
<b>12.</b>	<b>Oscillations of Liquid Columns</b>	<b>287</b>
12.1	Introduction	287
12.2	Theory	288
12.2.1	Infinite Liquid Columns	290
12.2.2	The Free Fluid Surface	291
12.2.3	Natural Frequencies	292
12.2.4	Finite Liquid Columns	292
12.2.5	Axially Damped Oscillations	294
12.2.6	Symmetric and Antimetric Oscillations	295
12.2.7	Resonance Detection and Flow Patterns	297
12.3	Experiments	302
12.3.1	Short Liquid Columns	302
12.3.2	Plateau Simulation	303
12.3.3	Automatic Resonance Detection	305
12.3.4	The LICOR Runs	308
12.4	Lateral Oscillations of Liquid Bridges	312
12.4.1	Damped Harmonic Oscillations	312
12.4.2	Periodic Lateral Deformations	314
12.4.3	Coupled Damped Oscillations	316
	References	321

<b>13. Microgravity Experiments</b>	
<b>in Sounding Rockets, Spacelab and EURECA</b> .....	323
13.1 TEXUS 1-39 .....	323
13.2 MAXUS 1-4.....	336
13.3 MiniTEXUS 1-6 .....	337
13.4 MASER 1-8 .....	338
13.5 SPAR I-X.....	340
13.6 TR-IA 1-7 .....	343
13.7 Skylab, May 1973 .....	345
13.8 Apollo-Soyuz Test Project (ASTP) .....	346
13.9 Spacelab 1 (STS-9) .....	347
13.10 Spacelab 3 (STS-51B) .....	348
13.11 Spacelab D-1 (STS-61A) .....	349
13.12 Spacelab D-2 (STS-55).....	351
13.13 IML-1 (STS-42) .....	353
13.14 Spacelab J (STS-47) .....	354
13.15 IML-2 (STS-65) .....	355
13.16 EURECA .....	357
13.17 MIR and FOTON .....	357
Bibliography .....	358
<b>Subject Index</b> .....	361

Capillary Surfaces

Shape — Stability — Dynamics, in Particular Under  
Weightlessness

Langbein, D.W.

2002, XVIII, 366 p., Hardcover

ISBN: 978-3-540-41815-3