

# PLANETARY LANDERS AND ENTRY PROBES

ANDREW J. BALL

The Open University

JAMES R. C. GARRY

Leiden University

RALPH D. LORENZ

Johns Hopkins University Applied Physics Laboratory

VIKTOR V. KERZHANOVICH

NASA Jet Propulsion Laboratory



**CAMBRIDGE**  
UNIVERSITY PRESS

# Contents

<i>Preface</i>	<i>page xi</i>
<i>Acknowledgements</i>	<i>xii</i>
<i>List of acronyms and abbreviations</i>	<i>xiii</i>
<b>PART I Engineering issues specific to entry probes, landers or penetrators</b>	<b>1</b>
1 Mission goals and system engineering	3
1.1 Systems engineering	3
1.2 Choice of landing site	7
2 Accommodation, launch, cruise and arrival from orbit or interplanetary trajectory	14
2.1 The launch environment	14
2.2 Transfer-trajectory choice	15
2.3 Arrival strategies	23
3 Entering atmospheres	24
3.1 Entry dynamics	24
3.2 Thermodynamics of entry	27
3.3 TPS technologies	31
3.4 Practicalities	32
4 Descent through an atmosphere	36
4.1 Overview and fundamentals	36
4.2 Extreme ballistic coefficients	36
4.3 Drag enhancement devices	39
4.4 Parachute types	40
4.5 Testing	44

4.6	Additional components of a descent control system	45
4.7	Mars – retro-rockets in atmosphere	45
5	Descent to an airless body	47
5.1	The gravity turn	48
5.2	Efficient descent	48
5.3	Realistic trajectories	48
5.4	Example – direct descent – Surveyor	49
5.5	Examples: Luna 16 and Apollo	50
5.6	Small bodies	50
5.7	Instrumentation	51
5.8	Powered re-ascent	54
5.9	Hover	54
5.10	Combined techniques – system engineering	55
6	Planetary balloons, aircraft, submarines and cryobots	56
6.1	Balloons	56
6.2	Powered aerobots (airships)	63
6.3	Aeroplanes and gliders	66
6.4	Other heavier-than-air concepts for aerial mobility	68
6.5	Submarines, hydrobots and cryobots	69
7	Arrival at a surface	71
7.1	Targeting and hazard avoidance	71
7.2	Landing gear	72
7.3	Penetration dynamics	78
7.4	Splashdown dynamics: Titan landers, Earth-return capsules	80
8	Thermal control of landers and entry probes	84
8.1	Surface coatings and radiation balance	85
8.2	Internal heat transfer	86
8.3	Thermal environment during descent	87
8.4	Thermal testing	91
8.5	Thermal modelling	91
9	Power systems	94
9.1	System requirements	94
9.2	Power and energy budgets	95
9.3	Radioisotope sources	96
9.4	Solar power	98
9.5	Battery technology	101
9.6	Other power sources	103

9.7	Power and thermal control	103
9.8	Nuts and bolts	104
10	Communication and tracking of entry probes	105
10.1	Entry probes: communication basics	107
10.2	Main telecom equation	112
10.3	Frequency measurements	114
10.4	Data transmission	115
10.5	Link budget	117
10.6	Tracking	117
11	Radiation environment	121
12	Surface activities: arms, drills, moles and mobility	124
13	Structures	130
14	Contamination of spacecraft and planets	132
14.1	Sources of contamination	134
14.2	Current regulations for spacecraft-borne bioload	136
14.3	Techniques for cleaning and sterilizing	136
14.4	Problems specific to spacecraft	143
14.5	Cleanliness as a separate goal	145
14.6	Sample return	146
<b>PART II</b>	<b>Previous atmosphere/surface vehicles and their payloads</b>	<b>147</b>
15	Destructive impact probes	151
16	Atmospheric entry probes	153
16.1	First Soviet Venera and Mars entry probes	153
16.2	Venera 4–8 (V-67, V-69, V-70 and V-72) entry probes	159
16.3	Pioneer Venus probes	159
16.4	VeGa AZ balloons	170
16.5	Galileo Probe	173
16.6	Huygens	175
17	Pod landers	177
17.1	Ranger Block 2 Seismo capsules	178
17.2	Luna 4–9, 13 (Ye-6 and Ye-6M) landers	179
17.3	Mars 2, 3, 6, 7 (M-71 and M-73) landers	185
17.4	Mars 96 Small Stations	186
17.5	Mars Pathfinder	190

17.6	Beagle 2	191
17.7	Mars Exploration Rovers	196
18	Legged landers	199
18.1	Surveyor landers	199
18.2	Apollo lunar modules	199
18.3	Luna 17, 21 (Ye-8) landers and the Lunokhods	203
18.4	Luna 15, 16, 18, 20 (Ye-8-5) landers	203
18.5	Luna 23, 24 (Ye-8-5M) landers	203
18.6	Soviet LK lunar lander	203
18.7	Venera 9–14 (4V-1) and VeGa (5VK) landers	203
18.8	Viking landers	203
18.9	Mars Surveyor landers	227
18.10	Mars Science Laboratory	234
19	Payload delivery penetrators	238
19.1	Mars 96 penetrators	240
19.2	Deep Space 2 Mars Microprobes	243
19.3	Lunar-A penetrators	245
20	Small body surface missions	247
20.1	Phobos 1F	247
20.2	NEAR Shoemaker	253
20.3	Rosetta lander Philae	253
20.4	Hayabusa (MUSES-C) and MINERVA	257
<b>PART III Case studies</b>		<b>261</b>
21	Surveyor landers	263
21.1	Design	264
21.2	Flight performance	265
22	Galileo probe	267
22.1	Equipment	268
22.2	Flight performance	270
23	Huygens	273
24	Mars Pathfinder and Sojourner	284
25	Deep Space 2 Mars Microprobes	289
26	Rosetta lander Philae	299
27	Mars Exploration Rovers: Spirit and Opportunity	304

27.1	The spacecraft	304
27.2	The rovers	307
27.3	Problems encountered	311
<i>Appendix: Some key parameters for bodies in the Solar System</i>		313
Atmosphere models		313
<i>Bibliography</i>		316
Engineering		316
Reference		319
Planetary sciences		319
Historical		320
Some useful web sites		321
<i>References</i>		323
<i>Index</i>		338