
Contents

1	Launching to Interplanetary Orbits	1
1.1	Launchers Overview	1
1.2	Launch Energy and Declination	2
1.3	Performance Estimation	6
1.4	LEO Performances	6
1.4.1	Ariane 5 LEO Performance	6
1.4.2	Soyuz LEO Performance	6
1.4.3	VEGA LEO Performance	6
1.4.4	Proton LEO Performance	7
1.4.5	Falcon LEO Performance	7
1.4.6	Atlas V LEO Performance	8
1.5	GTO Performances	8
1.5.1	Ariane 5 GTO Performance	8
1.5.2	Soyuz GTO Performance	8
1.5.3	PSLV-XL GTO Performance	8
1.5.4	Proton GTO Performance	8
1.5.5	Falcon 9 GTO Performance	8
1.5.6	Atlas V GTO Performance	9
1.6	Lunar Transfer Orbit Performances	9
1.6.1	Ariane 5 LTO Performance	9
1.6.2	Soyuz LTO Performance	9
1.6.3	Proton LTO Performance	9
1.6.4	Falcon 9 LTO Performance	9
1.6.5	Atlas V LTO Performance	9
1.7	Interplanetary Performances	10
1.7.1	Ariane 5 Escape Performance	10
1.7.2	Soyuz Escape Performance	10
1.7.3	Proton Escape Performance	10
1.7.4	Falcon 9 Escape Performance	10
1.7.5	Atlas V Escape Performance	11
1.8	Performance Summary Table	11
1.9	The Rocket Equation and Engine Performance	11
1.10	Parking Orbit Optimization	12
1.11	Examples	16
1.11.1	Lunar Mission	16
1.11.2	Mission to Mars	16
1.11.3	Mission to Neptune	17
	References	17
2	Transfer to a Planet	19
2.1	Positions of the Planets	19
2.2	Devising Trajectories to Other Planets	20

2.3	Launch Windows and C3 Values for Direct Transfers to the Planets	21
2.3.1	Direct Transfer to Mercury	22
2.3.2	Direct Transfer to Venus	22
2.3.3	Direct Transfer to Mars	23
2.3.4	Direct Transfer to Jupiter	24
2.3.5	Direct Transfer to Saturn	24
2.3.6	Direct Transfer to Uranus	27
2.3.7	Direct Transfer to Neptune	27
2.3.8	Direct Transfer to Pluto	29
2.4	Avoiding Mars Dust Storms	29
2.5	Return Missions	34
2.6	Examples	39
2.6.1	Mission to Mars	39
2.6.2	Mission to Neptune	39
	References	39
3	Gravity Assist Maneuvers	41
3.1	The Principle Behind Gravity Assists	41
3.2	Tisserand Graphs and Typical Gravity Assist Sequences	42
3.3	Gravity Assist Transfers to Mercury	45
3.4	Positions of the Outer Planets	46
3.5	Missions to the Outer Planets Using Gravity Assist Maneuvers	50
3.5.1	Gravity Assist Transfers to Saturn	50
3.5.2	Gravity Assist Transfers to Uranus	51
3.5.3	Gravity Assist Transfers to Neptune	52
3.5.4	Gravity Assist Transfers to Pluto	53
3.6	Recurring Gravity Assist Maneuvers Using Resonant Orbits	55
3.7	Examples	56
3.7.1	Mission to Saturn	56
3.7.2	Mission to Neptune	58
4	Deep-Space Maneuvers	59
4.1	High-Thrust Transfers	59
4.1.1	Mission to Mercury Using DSM	59
4.1.2	Mission to Venus Using DSM	59
4.1.3	Mission to Mars Using DSM	60
4.1.4	Mission to the Outer Planets Using DSM	61
4.2	Low-Thrust Transfers	63
4.2.1	Powering Low-Thrust Engines	64
4.2.2	Reducing Low-Thrust Transfer Times	65
4.2.3	Low-Thrust Transfers to the Inner Planets	66
4.2.4	Low-Thrust Transfers to the Outer Planets	67
4.3	Examples	70
4.3.1	Mission to Saturn	70
4.3.2	Mission to Neptune	71
5	Lunar Transfers	73
5.1	Characteristics of the Moon's Orbit	73
5.2	Direct Transfers	74
5.2.1	Transfer Time	74
5.2.2	Direct Transfers from an Ariane 5 Launch	75
5.2.3	Direct Transfers from a Soyuz Launch	77
5.2.4	Direct Transfers from a Proton Launch	77

5.2.5	Direct Transfers from a Cape Canaveral Launch	77
5.2.6	Direct Transfers from LEO	78
5.2.7	Direct Transfers from GTO	79
5.3	Free-Return Trajectories	84
5.4	Bi-Elliptic Transfers from GTO	86
5.5	Weak Stability Boundary Transfers from GTO	90
5.6	Low-Thrust Transfers to the Moon	96
5.6.1	Low-Thrust Transfers from LEO to the Moon	96
5.6.2	Low-Thrust Transfers from GTO to the Moon	97
5.7	Examples.	101
5.7.1	Low-Thrust Using Falcon-9	101
5.7.2	Lunar Transfer with Shared Ariane 5 Launch	101
5.7.3	Human Mission to the Moon	102
	Reference	102
6	Arrival Conditions	103
6.1	The B-Plane.	103
6.2	How the Operational Orbit Is Constrained by the Arrival Conditions.	105
6.3	Orbit Insertion	110
6.3.1	Gravity Loss	111
6.3.2	High-Thrust Insertion at the Inner Planets	111
6.3.3	Low-Thrust Insertion at the Inner Planets	111
6.3.4	High-Thrust Insertion at the Outer Planets	114
6.3.5	Low-Thrust Insertion at the Outer Planets	117
6.3.6	Lunar Orbit Insertion	119
6.4	Atmospheric Entry	122
6.4.1	Aspects of Atmospheric Entry	123
6.4.2	The Design of an Entry Probe	124
6.4.3	Entry at the Inner Planets	127
6.4.4	Entry at the Outer Planets	135
6.4.5	Entry at the Moons.	142
6.4.6	Phases of Atmospheric Entry	143
6.5	Powered Descent During Entry.	149
6.6	Powered Descent Without Atmosphere	152
6.6.1	Descent Orbit Insertion	153
6.6.2	Powered Descent Initiation or Braking Phase	154
6.6.3	Approach or Final Phase	157
6.6.4	Hovering	159
6.6.5	Terminal Descent	159
6.6.6	Descent ΔV	160
6.7	Examples.	162
6.7.1	Moon Orbiter Example	162
6.7.2	Moon Lander Example	162
6.7.3	Neptune Probe Example	163
	References	163
7	Planetary Orbits	165
7.1	General Characteristics	165
7.1.1	Kepler Parameters.	165
7.1.2	How Kepler Parameters Influence System Design.	166
7.1.3	Orbit Perturbations and Maintenance.	176
7.2	Sun-Synchronous Orbits	177

7.3	Frozen Orbits	183
7.4	Repeating Ground Track and Synchronous Orbits	187
7.5	Stationary Orbits	190
7.6	Critically Inclined and Molniya Orbits	191
7.7	Highly Elliptic Orbits	194
7.8	Multi-synch Orbits	197
7.9	Libration Point Orbits	198
7.10	End of Life Procedures	202
7.11	Examples	203
	7.11.1 Moon Orbiter Example	203
	7.11.2 Neptune Orbiter Example	203
8	Auxiliary Calculations	205
8.1	Eclipse Times	205
8.2	Earth Ground-Station Visibility	207
8.3	Surface Elements Visibility	211
8.4	ΔV Budgets and Margin Philosophies	213
8.5	Examples	217
	8.5.1 Moon Orbiter Example	217
	8.5.2 Neptune Mission Example	217
	Appendix A: Supporting Data for the Plots	219



<http://www.springer.com/978-3-319-26981-8>

Lunar and Interplanetary Trajectories

Biesbroek, R.

2016, XV, 227 p. 320 illus., 292 illus. in color.,

Hardcover

ISBN: 978-3-319-26981-8