

# Table of Contents

<b>List of Authors and Editors</b>	<b>xv</b>
<b>Preface</b>	<b>xxi</b>
<b>1 An Introduction to Human Spaceflight</b>	<b>1</b>
1.1 Humans in Space	3
1.2 The Life Cycle of Human Space Missions	8
1.3 The Space Mission Concept and Architecture	10
1.4 The Challenges	15
<b>2 Designing Human Space Missions</b>	<b>17</b>
2.1 Define Mission Objectives	19
2.2 Define Mission Requirements and Constraints	21
2.3 Develop Alternative Mission Concepts and Architectures	24
2.4 Identify System Drivers and Critical Requirements	48
2.5 Baseline a Mission Concept and Architecture	50
<b>3 The Space Environment—Hazards and Effects</b>	<b>53</b>
3.1 Operating in a Vacuum	55
3.2 Effects of the Nonionized Atmosphere	58
3.3 The Plasma Environment—Spacecraft Charging	62
3.4 Effects of Radiation	65
3.5 Micrometeoroids and Orbital Debris	73
3.6 Interplanetary Space	74
3.7 Design Example—Lunar Base	74
<b>4 Surface Environments</b>	<b>77</b>
4.1 The Moon	79
4.2 Mars	88
<b>5 Physiology of Spaceflight</b>	<b>103</b>
5.1 Setting Environmental Parameters	104
5.2 Metabolic Parameters and Related Inputs and Outputs	121
5.3 Other Physiological Factors	125
5.4 Lunar Base Example	130

<b>6</b>	<b>Human Factors of Crewed Spaceflight</b>	<b>133</b>
6.1	Defining the Role of Human Factors in Space Missions	134
6.2	Analyzing Tasks, Allocating Functions, and Assigning Workloads	139
6.3	Human Abilities and Limits	144
6.4	Analyzing Space and Surface Elements	148
6.5	Working with a Case Study—the Lunar Base	151
<b>7</b>	<b>Psychology of Spaceflight</b>	<b>155</b>
7.1	Basic Concepts	156
7.2	Designing the Psychological Aspect	159
7.3	Levying the Design	188
7.4	Conclusion	190
<b>8</b>	<b>Safety of Crewed Spaceflight</b>	<b>193</b>
8.1	Safety Design	194
8.2	Designing for Safety	196
8.3	Safety Analysis	200
8.4	Lunar Base Example	209
<b>9</b>	<b>Orbit Selection and Astrodynamics</b>	<b>213</b>
9.1	Mission Design	213
9.2	Keplerian Orbits	216
9.3	Options for Trajectories and Orbits	237
9.4	Lunar Base Example	266
<b>10</b>	<b>Entry, Descent, Landing, and Ascent</b>	<b>271</b>
10.1	Doing Mission Trades and Developing Requirements	273
10.2	Atmospheric Entry	279
10.3	Descent and Landing	302
10.4	Ascent	316
10.5	Lunar Base Example	328
<b>11</b>	<b>Designing and Sizing Space Elements</b>	<b>331</b>
11.1	Designing Space Elements	332
11.2	Review the Mission Statement and Mission Objectives	333
11.3	A Preliminary List of Requirements and Constraints	338
11.4	Create Preliminary Concepts for a Space Station	340
11.5	Select Orbit and Approach to Orbit Control	345
11.6	Select Flight Mode	346
11.7	Make Critical Choices for Subsystems	349
11.8	Develop Alternative Configurations	353
11.9	Assess Concepts for the Space Element	370
11.10	Select a Baseline Configuration	380
11.11	Design Example: “Minimum Growth Space Station”	380

<b>12</b>	<b>Transfer, Entry, Landing, and Ascent Vehicles</b>	<b>391</b>
12.1	Define Requirements and Constraints	391
12.2	Generate Vehicle Concepts	392
12.3	Select Options for Further Development	400
12.4	Develop Conceptual Designs for Selected Options	403
12.5	Evaluate Conceptual Designs and Select a Baseline	415
12.6	Vehicle Design for an Example Lunar Mission	415
<b>13</b>	<b>Designing, Sizing, and Integrating a Surface Base</b>	<b>421</b>
13.1	Determining the Mission Objectives	422
13.2	Developing the Surface Base	424
13.3	Selecting a Site and Laying Out a Base	429
13.4	Sizing and Integrating Base Zones and Elements	435
13.5	Assessing Cost and Complexity	440
13.6	Documenting and Iterating	441
13.7	Case Study: Surface Base at the Moon's South Pole	441
<b>14</b>	<b>Planetary Surface Vehicles</b>	<b>447</b>
14.1	Mobility System Concepts and Rationale	450
14.2	Designing Mobility Systems	453
14.3	Example of a Rover Design for the Lunar Base	462
<b>15</b>	<b>In-situ Resources</b>	<b>477</b>
15.1	Resources on Mars	480
15.2	Extracting Lunar Resources	502
15.3	Lunar Base Example	509
<b>16</b>	<b>Thermal Control</b>	<b>513</b>
16.1	Developing a Conceptual Design for a Thermal Control System	515
16.2	Fundamentals of Thermal Control	519
16.3	Hardware for Thermal Control	522
16.4	Thermal Environments	523
16.5	Tools for Thermal Analysis	524
16.6	Thermal Protection System	525
16.7	Passive Thermal Control	528
16.8	Active Thermal Control	529
16.9	Case Study—Mission to the Lunar South Pole	534
<b>17</b>	<b>Environmental Control and Life Support Systems (ECLSS)</b>	<b>539</b>
17.1	Requirements for the Life Support System	540
17.2	Technology Options	551
17.3	Developing a System Concept	562
17.4	Example of a Mission Design	567

<b>18</b>	<b>Crew Accommodations</b>	<b>575</b>
18.1	Designing Crew Accommodations for Space Missions	576
18.2	Mission Requirements and the Design Process	576
18.3	A Resource Model for Crew Accommodations	580
18.4	Crew Accommodations Subsystems	581
18.5	Tailoring the Model for the Shuttle, International Space Station, Moon, and Mars	596
<b>19</b>	<b>Attitude Determination and Control</b>	<b>607</b>
19.1	Designing the Attitude Determination and Control Subsystem (ADCS)	607
19.2	Establishing Control Modes and Requirements	614
19.3	Quantifying the Disturbance Environment	625
19.4	Selecting and Sizing ADCS Hardware	627
19.5	Defining the Control Algorithms	637
<b>20</b>	<b>Designing Power Systems</b>	<b>643</b>
20.1	Overview of Power Systems	645
20.2	Primary Power	646
20.3	Energy Storage	656
20.4	Power Management and Distribution (PMAD)	658
20.5	Design Example	660
<b>21</b>	<b>Structures</b>	<b>665</b>
21.1	Requirements for Space Structures	667
21.2	Establishing a Verification Plan	674
21.3	Special Considerations for Space Structures that House People	679
21.4	Design Options	681
21.5	Preliminary Layout and Sizing of Structures	689
21.6	Example: Sizing a Crew-Module Structure	695
<b>22</b>	<b>Extravehicular Activity (EVA) Systems</b>	<b>707</b>
22.1	Requirements for EVA Systems	710
22.2	EVA Systems and Operations Concepts	720
22.3	Interfaces	729
22.4	Developing a Design	730
22.5	Case Study: Providing EVA at a Lunar Base	731
<b>23</b>	<b>Space Robotics</b>	<b>739</b>
23.1	Basic Concepts of Robotics	740
23.2	Humans vs. Robots	742
23.3	Analyzing Functional and Operational Requirements	744

23.4	Planning and Controlling Space Robots	746
23.5	Key Design Issues for a Robotic System	747
23.6	Case Study: Robotic Rover for a Lunar Outpost	756
<b>24</b>	<b>Propulsion Systems</b>	<b>761</b>
24.1	Preliminary Design (Steps 1 and 2)	762
24.2	Selecting Potential Technologies (Step 3, Part 1)	765
24.3	Sizing the Vehicle (Step 3, Part 2)	769
24.4	Sizing the Thrust-generation System (Step 4)	781
24.5	Sizing the Propellant-handling System (Step 5)	791
24.6	Summarizing the Design Example	795
<b>25</b>	<b>Selecting Launch and Transfer Vehicles</b>	<b>797</b>
25.1	Selecting a Launch or Transfer Vehicle	798
25.2	Capabilities of Launch Vehicles	798
25.3	Capabilities of Transfer Vehicles	806
25.4	Environments for Launch or Transfer Vehicles	808
<b>26</b>	<b>Mission Operations for Crewed Spaceflight</b>	<b>811</b>
26.1	Developing a Baseline Operations Plan	814
26.2	Accomplishing the Mission Operations Functions	821
26.3	Mission Planning	826
26.4	Activity Planning and Development	830
26.5	Mission Control	836
26.6	Data Transport and Delivery	839
26.7	Navigation Planning and Analysis	842
26.8	Space Element Planning and Analysis	844
26.9	Payload Planning and Analysis	848
26.10	Payload Data Processing	851
26.11	Archiving and Maintaining the Mission Database	854
26.12	Systems Engineering, Integration, and Test	856
26.13	Computers and Communications Support	858
26.14	Developing and Maintaining Software	859
26.15	Managing Mission Operations	862
26.16	Planning Crew Activities and Training	865
<b>27</b>	<b>Command, Control, and Communications Architecture</b>	<b>869</b>
27.1	Designing the C <sup>3</sup> Architecture	870
27.2	Analyzing Requirements	871
27.3	Designing the Communications System	888
27.4	Design Example	899
27.5	Case Study—Lunar Mission	902

<b>28</b>	<b>Space Logistics Support</b>	<b>907</b>
28.1	Logistics Support in the Design Process	909
28.2	Determining the Overall Logistics Support Concept	912
28.3	Establishing Objectives, Requirements, and Constraints	915
28.4	Preliminary Logistics Support Concepts and Scenarios	917
28.5	Design Example and Early Supportability Assessment	929
<b>29</b>	<b>Estimating the Cost of Crewed Space Systems</b>	<b>933</b>
29.1	Overview of Cost Estimating	933
29.2	Parametric Cost Estimating	941
29.3	Other Cost Issues	951
29.4	Example—Rover Design for the Lunar Base	957
<b>30</b>	<b>International Crewed Missions</b>	<b>961</b>
30.1	The Need for International Cooperation	961
30.2	General Principles of Cooperative Missions	971
30.3	Development Processes for International Cooperation	972
30.4	Requirements and Constraints on International Crewed Missions	976
30.5	Elements of Agreements and International Management	977
30.6	Case Study	979
<b>31</b>	<b>Mars Design Example</b>	<b>981</b>
31.1	Designing the Mars Mission	983
31.2	Transfer Vehicle—Designing the Habitation and Lander	991
31.3	Estimating Mass and Power	998
31.4	The Next Iteration	999
<b>Appendix A</b>	<b>Inertias of Geometric Primitives</b>	<b>1003</b>
<b>Appendix B</b>	<b>Explanation of Earth Satellite Parameters</b>	<b>1007</b>
	<b>Index</b>	<b>1013</b>
	<b>Glossary of Acronyms</b>	