Human Spaceflight: Mission Analysis and Design



Edited by Wiley J. Larson United States Air Force Academy

Linda K. Pranke

LK Editorial Services

This book is published as part of the Space Technology Series, a cooperative activity of the United States Department of Defense and the National Aeronautics and Space Administration



The McGraw-Hill Companies, Inc.

New York St. Louis San Francisco Auckland Bogotá Caracas Lisbon London Madrid Mexico Milan Montreal New Delhi Paris San Juan Singapore Sydney Tokyo Toronto

Table of Contents

1

Lis	ist of Authors and Editors		xv
Pre	face		xxi
1	An Introduction to Human Spaceflight		
	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
2	Designing Human Space Missions		
	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
3	The Space Environment—Hazards and Effects		
	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
4	Surface Environments		
	4.1	The Moon	79
	4.2	Mars	88
5	Physiology of Spaceflight		103
	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

6	Human	Factors of Crewed Spaceflight	133
	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
7	Psychol	ogy of Spaceflight	155
	7.1	Basic Concepts	156
	7.2	Designing the Psychological Aspect	159
	7.3	Levying the Design	188
	7.4	Conclusion	190
8	Safety o	of Crewed Spaceflight	193
	8.1	Safety Design	194
	8.2	Designing for Safety	196
	8.3	Safety Analysis	200
	8.4	Lunar Base Example	209
9	Orbit Se	election and Astrodynamics	213
	9.1	Mission Design	213
	9.2	Keplerian Orbits	216
· .	9.3	Options for Trajectories and Orbits	237
1	9.4	Lunar Base Example	266
10	Entry, D	Descent, Landing, and Ascent	271
	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
11	Designi	ing and Sizing Space Elements	331
	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

vi

.

12	Trans	fer, Entry, Landing, and Ascent Vehicles	391
	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
13	Designing, Sizing, and Integrating a Surface Base		
	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
14	Planetary Surface Vehicles		447
	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
15	In-situ Resources		
	15.1	Resources on Mars	480
	15.2	Extracting Lunar Resources	502
	15.3	Lunar Base Example	509
16	Thermal Control		
	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
17	Environmental Control and Life Support Systems (ECLSS)		539
	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

viii

18	Crew A	ccommodations	575
	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
19	Attitud	e Determination and Control	607
	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
20	Designi	ing Power Systems	643
	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
21	Structu	res	665
	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
22	Extravehicular Activity (EVA) Systems		707
	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
23	Space Robotics		739
	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
24	Propulsion Systems		761
	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
25	Selecti	ng Launch and Transfer Vehicles	797
	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
26	Missio	on Operations for Crewed Spaceflight	811
	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
27	Command, Control, and Communications Architecture		869
	27.1	Designing the C ³ 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

28	Space L	ogistics Support	907
	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
29	Estimating the Cost of Crewed Space Systems		
	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
30	International Crewed Missions		
	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
31	Mars Design Example		981
	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
Appendix A		Inertias of Geometric Primitives	1003
Appendix B		Explanation of Earth Satellite Parameters	1007
Inde	x		1013
Glos	sary of A	Acronyms	

. . .

. Х