
Contents

Contributors	xv
Preface to the Second Edition	xix
Preface to the First Edition	xxi
Section 1 Futures of Aerospace	1
1.1 Potential Impacts of Global Technology and Resultant Economic Context on Aerospace Going Forward	1
1.2 Civilian Aeronautical Futures	2
1.3 Military Aeronautics Futures	4
1.4 Futures of Space Access	7
1.5 Aerospace beyond LEO	9
Bibliography	12
Section 2 Aircraft Systems	13
2.1 Introduction	13
2.2 Air Conditioning (ATA 21)	29
2.3 Electrical Power (ATA 24)	37
2.4 Equipment/Furnishings (ATA 25)	45
2.5 Fire Protection (ATA 26)	49
2.6 Flight Controls (ATA 27)	57
2.7 Fuel (ATA 28)	59
2.8 Hydraulic Power (ATA 29)	66
2.9 Ice and Rain Protection (ATA 30)	73
2.10 Landing Gear (ATA 32)	85
2.11 Lights (ATA 33)	86
2.12 Oxygen (ATA 35)	88
2.13 Pneumatic (ATA 36)	94
2.14 Water/Waste (ATA 38)	99
2.15 Airborne Auxiliary Power (ATA 49)	102
2.16 Avionic Systems	104
Acknowledgment	106
References	106
Further Reading	108
Section 3 Aerodynamics, Aeroelasticity, and Acoustics	113
3.1 Introduction	113
Part 1 The Physics of Drag and Lift Generation	114
3.2 Drag Generation	115
3.3 Lift Generation on Airfoils in Two-Dimensional Low-Speed Flow	116

3.4	Lift Generation on Finite-Span Wings in Low-Speed Flow . . .	119
3.5	Lift Generation on Slender Wings	120
3.6	Lift Generation in Transonic and Supersonic Flight	120
3.7	Lift Generation in Hypersonic Flight	120
3.8	Summary	120
	References	121
Part 2	Aerodynamic Analysis of Airfoils and Wings	122
	Notation	122
3.9	Airfoil Geometric and Aerodynamic Definitions	124
3.10	Wing Geometric and Aerodynamic Definitions	130
3.11	Fundamentals of Vector Fluid Dynamics	134
3.12	Fundamentals of Potential Flow	140
3.13	Elementary Boundary Layer Flow	149
3.14	Incompressible Flow Over Airfoils	156
3.15	Incompressible Flow Over Finite Wings	176
3.16	Shock Wave Relationships	187
3.17	Compressible Flow Over Airfoils	195
3.18	Compressible Flow Over Finite Wings	204
	References	213
Part 3	Aerodynamics of Low-Aspect-Ratio Wings and Bodies of Revolution	215
3.19	Incompressible Inviscid Flow Over a Low-Aspect-Ratio Wing at Zero Angle of Attack	215
3.20	Wave Drag	216
3.21	Equivalence Rule or Area Rule	216
3.22	Bodies of Revolution at Small Angle of Attack	217
3.23	Cross-Flow Analysis for Slender Bodies of Revolution at Small Angle of Attack	218
3.24	Lift on a Slender Wing	220
3.25	Low-Aspect-Ratio Wing-Body Combinations at Large Angle of Attack	221
	References	222
Part 4	Computational Aerodynamics	224
3.26	Governing Equations	224
3.27	Grid Generation	226
3.28	CFD Methods for the Compressible Navier–Stokes Equations	229
	References	242
Part 5	Aeronautical Measurement Techniques	244
3.29	General	244
3.30	Major Components of a Wind Tunnel	244
3.31	High-Speed Tunnels	245
3.32	Specialized Wind Tunnels	246
3.33	Flow Measurement Techniques	246
3.34	Density-Based Optical Flow Field Measurement Methods	253
3.35	Other Flow Field Measurement Methods	256
	References	256

Part 6	Fast Response Pressure Probes	258
	3.36 Probe Types and Ranges	258
	3.37 Probe Mounting	259
	3.38 Measuring Considerations	260
	3.39 Multisensor Probes	260
	3.40 Data Acquisition	261
	3.41 Postprocessing	262
	References	264
Part 7	Fundamentals of Aeroelasticity	266
	3.42 Aeroelasticity	266
	3.43 Aircraft Airworthiness Certification	270
	3.44 Aeroelastic Design	272
	Further Reading	272
Part 8	Computational Aeroelasticity	273
	3.45 Beginning of Transonic Small Perturbation Theory	273
	3.46 Development of Euler and Navier–Stokes–Based Computational Aeroelasticity Tools	275
	3.47 Computational Aeroelasticity in Rotorcraft	278
	3.48 Impact of Parallel Computers and Development of Three-Level Parallel Solvers	279
	3.49 Conclusion	281
	3.50 Appendix: Domain Decomposition Approach	282
	References	282
Part 9	Acoustics in Aerospace: Predictions, Measurements, and Mitigations of Aeroacoustics Noise	286
	3.51 Introduction	286
	3.52 Aeroacoustics Theoretical Background	286
	3.53 Computational Aeroacoustics and Future Directions	290
	3.54 Noise Measurements: Anechoic Chamber Experiments	292
	3.55 Applications	292
	Basic Terms	297
	References	297
Section 4	Aircraft Performance, Stability, and Control	299
Part 1	Aircraft Performance	300
	Notation	300
	4.1 Standard Atmosphere and Height Measurement	302
	4.2 Airspeed and Airspeed Measurement	313
	4.3 Drag and Drag Power (Power Required)	316
	4.4 Engine (Powerplant) Performance	321
	4.5 Level Flight Performance	326
	4.6 Climbing and Descending Flight	330
	4.7 Turning Performance	337
	4.8 Stall and Spin	339
	4.9 Range and Endurance	340

4.10	Takeoff and Landing Performance	346
4.11	Airplane Operations	352
	References	356
Part 2	Aircraft Stability and Control	358
	Notation	358
4.12	Mathematical Modeling and Simulation of Fixed-Wing Aircraft	359
4.13	Development of the Linearized Equations of Motion	367
4.14	Calculation of Aerodynamic Derivatives	375
4.15	Aircraft Dynamic Stability	378
4.16	Aircraft Response to Controls and Atmospheric Disturbances	382
	Further Reading	386
Part 3	Computational Optimal Control	388
4.17	Optimal Control Problem	388
4.18	Variational Approach to Optimal Control Problem Solution	390
4.19	Numerical Solution of the Optimal Control Problem	393
4.20	User Experience	398
	References	408
Section 5	Avionics and Air Traffic Management Systems	411
	Acronyms	411
Part 1	The Electromagnetic Spectrum	420
5.1	Radio Waves in a Vacuum	420
5.2	Antennas and Power Budget of a Radio Link	421
5.3	Radio Wave Propagation in the Terrestrial Environment	422
5.4	Electromagnetic Spectrum and Its Management	424
	References	427
Part 2	Aircraft Environment	428
5.5	Typical Flight Profile for Commercial Airplanes	428
5.6	The Atmosphere	429
5.7	Other Atmospheric Hazards	437
5.8	The Ionosphere	440
	References	440
Part 3	Electromagnetic Compatibility	441
5.9	Introduction	441
5.10	Background of EM Coupling	441
5.11	EM Environment and EMC Standards	444
5.12	EMC Tools	446
5.13	Engineering Method	448
5.14	Conclusion	449
	References	451

Part 4	Introduction to Radar	452
	5.15 Historical Background	452
	5.16 Basic Principles	452
	5.17 Trends in Radar Technology	457
	5.18 Radar Applications to Aeronautics	459
	5.19 Overview of Military Requirements and Specific Developments	461
Part 5	Avionics Electro-Optical Sensors	462
	5.20 Introduction	462
	5.21 Fundamental Physical Laws	462
	5.22 IR Sensors	464
	5.23 Passive Optoelectronic Systems	465
	5.24 NVIS Technology Overview	470
	5.25 NVIS Compatibility Issues	474
	5.26 Airborne Lasers	474
	References	480
Part 6	Optical Fibers	481
	5.27 Optical Fiber Theory and Applications	481
	References	488
Part 7	Aircraft Flight Control Systems	489
	5.28 Foreword	489
	5.29 Flight Control Objectives and Principles	489
	5.30 Flight Control Systems Design	498
	5.31 Airbus Fly-by-Wire: An Example of Modern Flight Control	503
	5.32 Some Control Challenges	514
	5.33 Conclusion	516
	References	516
Part 8	Modern Avionics Architectures	518
	5.34 Introduction to Avionics	518
	5.35 Requirements for Avionics	520
	5.36 Physical Architectures	520
	5.37 Avionics Logical Architecture	524
	5.38 Avionics Example: The Airbus A320 Flight Control System	530
	Further Reading	532
Part 9	Aeronautical Communication Systems	533
	5.39 Introduction	533
	5.40 Evolutions	533
	5.41 Aeronautical Radio Communication Types	534
	5.42 Aeronautical Communication System Design	535
	5.43 VHF Voice Communications	544
	5.44 VHF Datalink Communications	545
	5.45 HF Communication System	547
	5.46 Satellite Communication System	549

5.47	Military Aeronautical Communications	551
5.48	Future Trends	551
	References	553
Part 10	Ground Radio Navigation Aids	554
5.49	Introduction	554
5.50	Line-of-Sight Positioning	554
5.51	Calculation of Aircraft Position	555
5.52	Air Navigation and Landing Aids	560
	References	567
Part 11	Inertial Navigation Systems	568
5.53	Introduction	568
5.54	Inertial Sensors	569
	References	586
Part 12	Alternative Sensors and Multisensor Navigation Systems	587
5.55	Introduction	587
5.56	Vision-Based Navigation	587
5.57	Integrated Navigation Systems	590
	References	597
Part 13	Global Navigation Satellite Systems	598
5.58	GNSS Segments	598
5.59	GNSS Observables	599
5.60	GPS Error Sources	603
5.61	UERE Vector and DOP Factors	607
5.62	GNSS Performance Requirements in Aviation	608
5.63	GNSS Augmentation Strategies in Aviation	610
	References	615
Part 14	Airborne Separation Assurance and Collision Avoidance	617
5.64	Introduction	617
5.65	Rules of AIR	617
5.66	Airspace Categories and Classes	617
5.67	Separation Standards	618
5.68	Collision Detection and Avoidance	619
5.69	Conflict Detection and Resolution Approaches	623
5.70	SA&CA Technologies	625
5.71	Conflict Resolution Heuristics	628
5.72	Automatic Dependent Surveillance	632
5.73	Multilateration Systems	634
	References	635
Part 15	Air Traffic Management Systems	637
5.74	General Layout of ATM Systems	637
5.75	Fundamental ATM System Design Drivers	638
5.76	Airspace Structure	639
5.77	ATM Telecommunications Infrastructure	640

5.78	ATM Surveillance Infrastructure	642
5.79	Meteorological Services	642
5.80	Trajectory Design	646
5.81	CNS+A Evolutions	647
	References	649
Part 16	Aerospace Systems and Software Engineering	652
5.82	Introduction	652
5.83	Software Life-Cycle Process	652
5.84	Software Requirements	654
5.85	Software Design	656
5.86	Aerospace Software Verification and Validation	657
5.87	Tools for Safety and Reliability Assessment	664
5.88	Certification Considerations for Aerospace Systems	669
	References	670
Part 17	Aviation Human Factors Engineering	671
5.89	Human Performance Modeling	671
5.90	Human Factors Engineering Program	674
5.91	Techniques for Task Analysis	676
5.92	Design Considerations	679
5.93	Design Evaluation	681
	References	685
Section 6	Aeronautical Design	687
6.1	Definitions	687
6.2	Introduction	687
6.3	Overall Approach	687
6.4	Government Regulations	696
6.5	Conceptual Design	703
6.6	Military Aircraft Design	730
6.7	Commercial and Civil Aircraft Design	731
6.8	Life Cycle Cost (LCC)	733
6.9	Commercial Aircraft Operating Costs	736
6.10	Unmanned Air Vehicles	739
6.11	Lighter-Than-Air Vehicles (LTA)	743
6.12	V/STOL Air Vehicles	745
6.13	Performance	753
	References	769
	Further Reading	769
Section 7	Spacecraft Systems	771
Part 1	Space Missions	772
7.1	Introduction	772
7.2	Orbits	776
7.3	Satellite Missions	777

7.4	Launch Vehicles	801
7.5	Ground Segment	803
	References	805
Part 2	Test and Product Certification of Space Vehicles	806
7.6	Validation Basics	806
7.7	Verification Basics	807
7.8	Requirements Development Basics	808
7.9	Certification Requirements and Test Plan Development	808
7.10	Verification Methods	809
7.11	Test Basics	810
7.12	Compliance Documents	811
7.13	TLYF Overview	816
Part 3	Space Safety Engineering and Design	820
7.14	Introduction	820
7.15	Unmanned Space Systems Design and Engineering	823
7.16	Crewed Space Systems Design and Engineering	823
7.17	Combustion and Materials Engineering and Safety	826
7.18	Suborbital Flight Systems, Spaceplanes, Hypersonic Transport, and New Uses of the “Protozone” or “Near Space”	827
7.19	Launch Site Design and Safety Standards	829
7.20	Licensing and Safety Controls and Management for Various Types of Launcher Systems	829
7.21	Air and Space Traffic Control and Management	829
7.22	Atmospheric and Environmental Pollution	830
7.23	Orbital Debris Concerns and Tracking and Sensor Systems	831
7.24	Cosmic Hazards and Planetary Defense and Safety	832
7.25	Systems Engineering and Space Safety	833
7.26	Future Trends in Space Safety Engineering, Design, and Study	835
7.27	Conclusions	835
	References	836
Part 4	Spacecraft for Human Operation and Habitation	838
7.28	Introduction	838
7.29	Premium Placed on Mass and Volume	838
7.30	Common Attributes of Manned Spacecraft	838
7.31	Optimization of Humans with Machines	844
7.32	Human Spacecraft Configuration	844
7.33	Space Vehicle Architecture	852
7.34	ISS Crew Compartment Design	855
7.35	Systems	858
7.36	Summary	879
	References	880

Section 8	Astrodynamics	881
	Notation	881
	8.1 Orbital Mechanics	882
	8.2 Orbital Maneuvers	893
	8.3 Earth Orbiting Satellites	903
	8.4 Interplanetary Missions	916
	References	928
Section 9	Rockets and Launch Vehicles	929
	9.1 Rocket Science	929
	9.2 Propulsion Systems	949
	9.3 Launch Vehicles	970
	References	976
Section 10	Earth's Environment and Space	977
Part 1	The Earth and Its Atmosphere	978
	10.1 The Earth in Space	978
	10.2 Properties of the Earth's Atmosphere	978
	10.3 How the Earth's Atmosphere Works	980
	10.4 Atmospheric Dynamics and Atmospheric Models	983
	10.5 Electrical Phenomena in the Atmosphere	986
	References	987
Part 2	The Near-Earth Space Environment	988
	10.6 Background	988
	10.7 The Plasma Environment	989
	10.8 The Neutral Gas Environment	992
	10.9 The Vacuum Environment	993
	10.10 The Radiation Environment	993
	10.11 The Micrometeoroid and Space Debris Environment	996
	References	996
Part 3	The Solar System	997
	10.12 Physical Properties of the Planets	997
	10.13 Space Age Discoveries	997
	References	1003
Part 4	The Moon	1004
	10.14 Origin of the Moon	1004
	10.15 Orbital Parameters	1005
	10.16 Lunar Geography	1006
	10.17 Lunar Geology	1007
	10.18 Physical Surface Properties	1010
	10.19 Lunar Surface Environment	1016
	References	1020

Part 5	Mars	1021
	10.20 Orbital Characteristics	1021
	10.21 Solid Geophysical Properties and Interiors	1021
	10.22 Surface and Subsurface	1023
	10.23 Atmosphere	1027
	10.24 Satellites	1029
	10.25 Search for Life on Mars	1029
	10.26 Exploration	1030
	References	1031
Part 6	The Sun–Earth Connection	1033
	10.27 Introduction	1033
	10.28 The Sun and the Heliosphere	1033
	10.29 Structure and Dynamics of the Magnetospheric System	1036
	10.30 The Solar–Terrestrial Energy Chain	1037
	10.31 Dynamics of the Magnetosphere-Ionosphere- Atmosphere System	1038
	10.32 Importance of Atmospheric Coupling	1042
	10.33 Sun–Earth Connections and Human Technology	1043
	10.34 Summary	1044
	Further Reading	1045
Part 7	Space Debris	1046
	10.35 Introduction	1046
	10.36 Spatial Distribution of Space Debris	1048
	10.37 The Collision Risk	1050
	10.38 The Geostationary Orbit	1052
	10.39 Long-Term Evolution of the Space Debris Environment and Mitigation Measures	1052
	References	1054
	Further Reading	1054
Section 11	Spacecraft Subsystems	1055
Part 1	Attitude Dynamics and Control	1056
	11.1 Introduction	1056
	11.2 Rigid-Body Dynamics	1056
	11.3 Orientation Kinematics	1063
	11.4 Attitude Stabilization	1071
	11.5 Spin Stabilization of an Energy-Dissipating Spacecraft ...	1075
	11.6 Three-Axis Stabilization	1076
	11.7 Disturbance Torques	1077
	11.8 Spacecraft with a Fixed Momentum Wheel and Thrusters ...	1083
	11.9 Three-Axis Reaction Wheel System	1091
	11.10 Control Moment Gyroscope	1095
	11.11 Effects of Structural Flexibility	1098

	11.12 Attitude Determination	1103
	References	1106
Part 2	Observation Payloads	1108
	11.13 Overview	1108
	11.14 Observational Payload Types	1109
	11.15 Observational Payload Performance Figures of Merit ...	1123
	References	1126
Part 3	Spacecraft Structures	1128
	11.16 Role of Spacecraft Structures and Various Interfaces	1128
	11.17 Mechanical Requirements	1130
	11.18 Space Mission Environment and Mechanical Loads	1131
	11.19 Project Overview: Successive Designs and Iterative Verification of Structural Requirements	1134
	11.20 Analytical Evaluations	1136
	11.21 Test Verification, Qualification, and Flight Acceptance ...	1137
	11.22 Satellite Qualification and Flight Acceptance	1138
	11.23 Materials and Processes	1139
	11.24 Manufacturing of Spacecraft Structures	1141
	11.25 Composites	1142
	11.26 Composite Structures	1143
	References	1145
Part 4	Satellite Electrical Power Subsystem	1147
	11.27 Introduction	1147
	11.28 Solar Arrays	1154
	11.29 Batteries	1166
	11.30 Power Control Electronics	1176
	11.31 Subsystem Design	1180
	Acknowledgments	1184
	References	1184
Part 5	Systems Engineering, Requirements, Independent Verification and Validation, and Software Safety for Aerospace Systems	1185
	11.32 Developing Software for Aerospace Systems	1186
	11.33 Impact of Poorly Written Requirements	1188
	11.34 Benefit of Requirements Analysis	1189
	11.35 Application of Independent Verification and Validation ...	1189
	11.36 Consequences of Failure	1190
	11.37 Likelihood of Failure	1191
	11.38 General IV&V Techniques	1191
	11.39 Software Safety	1193
	11.40 Certification	1199
Part 6	Thermal Control	1200
	11.41 Introduction	1200
	11.42 Heat Transfer	1202

11.43	Thermal Analysis	1210
11.44	Thermal Control Techniques	1215
11.45	Spacecraft Thermal Design	1219
	Further Reading	1224
Part 7	Communications	1226
11.46	Introduction	1226
11.47	Basic Units and Definitions in Communications Engineering	1226
11.48	Frequency Allocations and Some Aspects of the Radio Regulations	1227
11.49	Electromagnetic Waves, Frequency, and Polarization Selection for Satellite Communications	1229
11.50	Link Consideration	1233
11.51	Communications Subsystem of a Communications Satellite	1238
11.52	Some Common Modulation and Access Techniques for Satellite Communications	1244
11.53	Satellite Capacity and the Sizing of Satellites	1254
	Further Reading	1256
Section 12	Spacecraft Design	1257
Part 1	Design Process and Design Example	1258
12.1	Spacecraft Design Process	1258
12.2	Spacecraft Design Example	1259
	Further Reading	1284
Part 2	Concurrent Engineering	1285
12.3	Introduction	1285
12.4	Concurrent Engineering Methodology	1288
12.5	Summary	1326
	References	1326
Part 3	Small Spacecraft Overview	1328
12.6	Introduction	1328
12.7	History and Evolution of Small Spacecraft	1329
12.8	Programmatic Considerations	1333
12.9	Life Cycle Considerations	1337
12.10	Small Spacecraft Technologies	1340
12.11	Case Studies	1343
12.12	Conclusion	1346
	Summary	1346
	References	1346
	Index	1349