

McGraw-Hill STANDARD HANDBOOKS

The Standard Handbook for Aeronautical and Astronautical Engineers



MARK DAVIES
EDITOR-IN-CHIEF

THE STANDARD HANDBOOK FOR AERONAUTICAL AND ASTRONAUTICAL ENGINEERS

Mark Davies Editor-in-Chief

McGRAW-HILL

New York Chicago San Francisco Lisbon London Madrid
Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto

Library of Congress Cataloging-in-Publication Data

The standard handbook for aeronautical and astronautical engineers / Mark Davies, editor-in-chief.

p. cm.

Includes index.

ISBN 0-07-136229-0

1. Aerospace engineering—Handbooks, manuals, etc. I. Davies, Mark, date.
TL509.S664 2002
629.1—dc21

2002032551

Copyright © 2003 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 0 DOC/DOC 0 8 7 6 5 4 3 2

ISBN 0-07-136229-0 (MH)

ISBN 0-7680-0915-4 (SAE)

The sponsoring editor for this book was Shelley Ingram Carr and the production supervisor was Sherri Souffrance. It was set in Times Roman by Pro-Image Corporation.

Printed and bound by RR Donnelley.

Sections 2, 3, 4, 5, and 6 of *The Standard Handbook for Aeronautical and Astronautical Engineers* were edited, adapted, and updated specifically for this Work from *Mechanical Engineer's Reference Book*, 12th ed., edited by E. H. Smith (1994), published by Butterworth-Heinemann, a division of Reed Education and Professional Publishing Ltd., and Society of Automotive Engineers, Warrendale, PA 15096.

McGraw-Hill books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please write to the Director of Special Sales, McGraw-Hill Professional, Two Penn Plaza, New York, NY 10121-2298. Or contact your local bookstore.

This book is printed on acid-free paper.

Information contained in this work has been obtained by The McGraw-Hill Companies, Inc. ("McGraw-Hill") from sources believed to be reliable. However, neither McGraw-Hill nor the authors guarantee the accuracy or completeness of any information published herein or that such information is current, and neither McGraw-Hill nor the authors are responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and the authors are supplying information but are not attempting to render engineering, design, or other professional services. If such services are required, the assistance of an appropriate professional should be sought. By way of example and not limitation, the services of a professional should be sought if the design or manufacture of any aircraft or equipment needs certification or if compliance with any applicable code, standard, or regulatory requirement needs to be determined.

**THE STANDARD
HANDBOOK FOR
AERONAUTICAL AND
ASTRONAUTICAL
ENGINEERS**

LIST OF CONTRIBUTORS

Jean-Paul Aguttes *Head of Plateau for Orbital Systems Architecture, Centre National d'Etudes Spatiales, France* (SECTION 11)

Aydin Akdeniz *Technical Fellow—Structures, Service Engineering, Commercial Aviation Services, Boeing, USA* (SECTION 18)

Dennis H. Bacon *Consultant and Technical Author, UK* (SECTION 3)

D. N. Baker *Laboratory for Atmospheric and Space Physics, University of Colorado, 392 UCB, Boulder, Colorado 80309-0392, USA* (SECTION 16)

John Barron *Lecturer, Department of Engineering, University of Cambridge, UK* (SECTION 2)

Christopher Beards *Consultant and Technical Author, UK* (SECTION 3)

Frederic Boniol *Research Engineer, ONERA, France* (SECTION 11)

Daniel Boscher *Head of the Radiations and Charge Effects Unit, ONERA/DESP, France* (SECTION 11)

Dominique Brière *Head of Flight Control and Automatic Flight Control System Department, Airbus, France* (SECTION 11)

J. P. Catani *Engineer/Head of Department Power Supply and Electromagnetic Compatibility, Centre National d'Etudes Spatiales, France* (SECTION 11)

Florent Christophe *Deputy Head of Department Electromagnetism and Radar, ONERA, France* (SECTION 11)

Nicholas Colford *Human Factors Engineer, UK* (SECTION 15)

Jonathan Cooper *Professor of Engineering, Manchester School of Engineering, University of Manchester, UK* (SECTION 9)

M. Crokaert *Doctor in Atomic Physics—Engineer, Centre National d'Etudes Spatiales, France* (SECTION 11)

Tara Dalton *Senior Research Fellow, Department of Mechanical and Aeronautical Engineering, University of Limerick, Ireland* (SECTION 15)

Glyn Davies *Senior Research Fellow, Department of Aeronautics, Imperial College of Science Technology and Medicine, UK* (SECTION 9)

Mark Davies *Head, Department of Mechanical & Aeronautical Engineering, University of Limerick, Ireland* (SECTIONS 2–4, 6)

David Deering *Space Systems Engineer, Ireland* (SECTION 15)

Scott Eberhardt *Department of Aeronautics and Astronautics, University of Washington, USA* (SECTION 7)

Peter Eckart *Division of Astronautics, Technical University of Munich, Germany* (SECTION 16)

- Duncan T. Enright** *Commissioning Editor, Butterworth-Heinemann, Oxford* (SECTION 2)
- Jack Foisseau** *Head of Modelling and Requirement Engineering Unit/Engineer, ONERA, France* (SECTION 11)
- Charles J. Fraser** *Reader in Mechanical Engineering, UK* (SECTIONS 4, 6)
- James T. Garris** *Boeing Commercial Airlines, USA* (SECTION 18)
- Francis C. Gideon, Jr.** *Safety and Management Consultant, USA* (SECTION 17)
- Daniel S. Goldin** *Former NASA Administrator, USA* (SECTION 1)
- Philippe Guyot** *Space Engineering Department Manager, ALCATEL, France* (SECTION 11)
- Jeremy F. Haines** *Principal Engineer, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)
- Rüdiger Jehn** *European Space Agency, Germany* (SECTION 16)
- Michael W. Jenkins** *Professor—Aerospace Design, School of Aerospace Engineering, Georgia Institute of Technology, USA* (SECTION 13)
- Bryan P. Kesterson** *Associate Technical Fellow—Human Factors, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)
- Harry A. Kinnison** *(Retired) Engineer, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)
- Phillip J. Kolczynski** *California Attorney at Law, USA* (SECTION 17)
- G. Komatsu** *International Research School of Planetary Sciences, Universita' d'Annunzio, Italy* (SECTION 16)
- Nick Larter** *Consultant, Ireland* (SECTION 15)
- R. Ken Livesley** *Lecturer, Department of Engineering, University of Cambridge, UK* (SECTION 2)
- Fraidoon Mazda** *Northern Telecom, UK* (SECTION 2)
- John S. Milne** *Professor, Department of Mechanical Engineering, Dundee Institute of Technology, Scotland* (SECTION 6)
- Jean-Claude Mollier** *Head of Department "Systemes Electronics Photoniques," SUPAERO, France* (SECTION 11)
- Roy Y. Myose** *Professor, Wichita State University, USA* (SECTION 14)
- Andrew J. Niven** *Lecturer, Department of Mechanical and Aeronautical Engineering, University of Limerick, Ireland* (SECTION 10)
- Ben Noltingk** *Consultant, UK* (SECTION 6)
- Ahmed K. Noor** *Eminent Scholar, William E. Lobeck Professor of Aerospace Engineering and Director, Center for Advanced Engineering Environments, Old Dominion University and Adjunct Professor of Aerospace Engineering, University of Florida, USA* (SECTION 1)
- Robert Paine** *Department of Engineering and Product Design, University of Central Lancashire, UK* (SECTION 3)
- J. P. Parmantier** *Doctor/Engineer in Electromagnetism, ONERA, France* (SECTION 11)
- Marc Pelegrin** *Doctor-es-Sciences Automatics, FEDESPACE, France* (SECTION 11)
- John D. Phillips** *USA* (SECTION 17)
- Donald W. Pitts** *Chairman, National Safety and Training Committee, Allied Pilots Association, USA* (SECTION 17)

- Sylvain Prudhomme** *Head of Identification and Control Research Group—System and Control Dynamics Department, ONERA, France* (SECTION 11)
- Navaal Ramdin** *Marketing—Propulsion Specialist, Boeing, USA* (SECTION 18)
- William L. Rankin** *Technical Fellow—Human Factors, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)
- Etienee Rapp** *Physics Engineer, Centre National d'Etudes Spatiales, France* (SECTION 11)
- Ian Robertson** *Change Management Consultant, Digital Equipment Corporation, UK* (SECTION 5)
- Michael J. Rycroft** *Cambridge Atmospheric, Environmental and Space Activities and Research, UK* (SECTION 16)
- Dieter Scholz** *University of Applied Sciences, Hamburg, Germany* (SECTION 12)
- Jerry Jon Sellers** *US Airforce, USA* (SECTION 8)
- Frank H. Snapp** *Consultant, Aviation Safety, USA* (SECTION 17)
- Steven L. Sogg** *Human Factors Specialist, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)
- Constantinos Stavrinidis** *Head of Mechanical Engineering Department, ESTEC, European Space Agency, The Netherlands* (SECTION 9)
- Lori Straus** *Lead Engineer—Organic & Inorganic Finishes, Boeing Materials Technology, Boeing* (SECTION 18)
- Robert L. Sumwalt, III** *Aviatrends, USA* (SECTION 17)
- Douglas G. Thomson** *Department of Aerospace Engineering, University of Glasgow, Scotland* (SECTION 10)
- William Tsai** *Associate Technical Fellow, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing* (SECTION 18)
- Peter Tucker** *Formerly Principal Lecturer, Department of Mechanical and Production Engineering, Preston Polytechnic, UK* (SECTION 3)
- Samuel L. Venneri** *Chief Technologist NASA Headquarters, USA* (SECTION 1)
- Pascal Willis** *NASA Jet Propulsion Laboratory, Pasadena California, USA* (SECTION 15)
- Gordon Young** *Director, Information Technology Department, University of Limerick, Ireland* (SECTION 5)
- Trevor M. Young** *Lecturer, Department of Mechanical and Aeronautical Engineering, University of Limerick, Ireland* (SECTION 10)
- Adel S. Zeki** *Senior Specialist Engineer, Maintenance Engineering Technical Services, Commercial Aviation Services, Boeing, USA* (SECTION 18)

PREFACE

The Standard Handbook for Aeronautical and Astronautical Engineers represents the efforts of many people working toward the common goal of amalgamating aeronautical and astronautical engineering into a single handbook. This is the first publication of such a book. A handbook on only astronautical was published by the same publishers in the early 1960s, which now represents a fascinating insight into the minds of those early pioneers.

The challenge to put the aeronautical and astronautical together was considerable. Although they overlap in so many ways, they also have many differences that needed to be addressed. The publisher's brief was for a book that successfully brought about this combination and that would be of value to professional engineers and engineering students alike. It must, therefore, cover something of every aspect of the vast spectrum of knowledge and methods that is aerospace engineering. Working between the covers of a book that can be carried by an unaided individual, of average strength, has meant that much cannot be included.

At an early stage in the *Handbook's* development, I decided that there would not be sufficient pages available to do justice to the military aspects of aerospace engineering. Consequently, the reader will not find many references to the military for the aeronautical and, similarly, for astronautical observation. Perhaps 75% of the book's contents would be on most engineers' list of essential engineering, the remaining 25% is there because of the section editors' and my opinions and prejudices.

The *Handbook* opens with a look at what the future may hold for the development of aeronautical and space systems. This sets the scene for what is to follow. Before addressing these issues directly, there are five sections on basic engineering science and mathematics that are the foundation of aerospace operations and design. Applications have been excluded, for the most part, from these sections to emphasize their generality. In the specialist section, wherever possible, aeronautical and space issues have been addressed in the same section, as in Aerospace Structures (Section 9) and Avionics and Astrionics (11); elsewhere, they have been divided, as in Aeronautical Propulsion (7) and Rockets and Launch Vehicles (8). Subsystems for aircraft are covered in a single section (12); whereas for spacecraft, they are part of Section 15. Because aircraft design is more standardized and mature, it occupies its own section (13). Astrodynamics (14) and Spacecraft (15) are unique to space, whereas the discussions on safety (17) and maintenance (18) are unique to aircraft.

Due to its limited size, the book cannot give a definitive account of any specific area. Thus experienced aerodynamicists may not find everything of interest in the aerodynamics section; nevertheless, they will find much of interest, for example, in the structures sections—the very structures that interact with the aerodynamic forces.

In this, the first edition, I feel that only the first stage in the journey to provide a comprehensive handbook has been made. Lionel Marks' *Standard Handbook for*

Mechanical Engineers, in print through many editions for almost a century, is a reference that has been invaluable to that discipline. It is my hope that one day I will have made a similar contribution to aeronautical and astronautical engineering.

For the present, I thank all of those who have helped in this endeavor, beginning with my commissioning editor, Shelley Carr, with whom, at times I have been in daily correspondence; she never wavered in her confidence and support for me, or if she did, I never knew. Then, I thank all of the section editors, the contributors, all of their colleagues and students who have helped, all of the institutes and companies that employ them, and my own institution, the University of Limerick, and my family: Judith, Elisabeth, and Helena.

CONTENTS

List of Contributors	xxi
Preface	xxv

Section 1. New Vision for Future Aerospace Vehicles and Systems 1.1

- 1.1. Learning from Living Systems / 1.1
- 1.2. Revolutionary Vehicles / 1.3
- 1.3. Future Space Transportation / 1.6
- 1.4. Future Airspace System / 1.7
- 1.5. Needed: Intellectual Infrastructure / 1.11
- 1.6. Smart Vehicle, Heal Thyself / 1.12
- 1.7. Working for More Secure Airspace / 1.14

Section 2. Engineering Mathematics, Units, Symbols, and Constants 2.1

Part 1. Trigonometric Functions and General Formulae

- 2.1. Mathematical Signs and Symbols / 2.2
- 2.2. Trigonometric Formulae / 2.4
- 2.3. Trigonometric Values / 2.5
- 2.4. Approximations for Small Angles / 2.6
- 2.5. Solution of Triangles / 2.6
- 2.6. Spherical Triangle / 2.7
- 2.7. Exponential Form / 2.7
- 2.8. De Moivre's Theorem / 2.7
- 2.9. Euler's Relation / 2.7
- 2.10. Hyperbolic Functions / 2.7
- 2.11. Complex Variable / 2.8
- 2.12. Cauchy–Riemann Equations / 2.9
- 2.13. Cauchy's Theorem / 2.9
- 2.14. Zeroes, Poles, and Residues / 2.9
- 2.15. Some Standard Forms / 2.10
- 2.16. Coordinate Systems / 2.10
- 2.17. Transformation of Integrals / 2.11
- 2.18. Laplace's Equation / 2.11
- 2.19. Solution of Equations / 2.12
- 2.20. Method of Least Squares / 2.14

Part 2. Calculus

- 2.21. Derivative / 2.16
- 2.22. Maxima and Minima / 2.16
- 2.23. Integral / 2.17
- 2.24. Derivatives and Integrals / 2.18

- 2.25. Standard Substitutions / 2.19
- 2.26. Reduction Formulae / 2.19
- 2.27. Numerical Integration / 2.20
- 2.28. Vector Calculus / 2.21

Part 3. Series and Transforms

- 2.29. Arithmetic Series / 2.23
- 2.30. Geometric Series / 2.23
- 2.31. Binomial Series / 2.23
- 2.32. Taylor's Series / 2.23
- 2.33. Maclaurin's Series / 2.24
- 2.34. Laurent's Series / 2.24
- 2.35. Power Series for Real Variables / 2.24
- 2.36. Integer Series / 2.25
- 2.37. Fourier Series / 2.25
- 2.38. Rectified Sine Wave / 2.26
- 2.39. Square Wave / 2.26
- 2.40. Triangular Wave / 2.27
- 2.41. Sawtooth Wave / 2.27
- 2.42. Pulse Wave / 2.27
- 2.43. Fourier Transforms / 2.27
- 2.44. Laplace Transforms / 2.29

Part 4. Matrices and Determinants

- 2.45. Linear Simultaneous Equations / 2.30
- 2.46. Matrix Arithmetic / 2.30
- 2.47. Eigenvalues and Eigenvectors / 2.31
- 2.48. Coordinate Transformation / 2.32
- 2.49. Determinants / 2.32
- 2.50. Properties of Determinants / 2.33
- 2.51. Numerical Solution of Linear Equations / 2.33

Part 5. Differential Equations

- 2.52. Notation and Definitions / 2.35
- 2.53. Ordinary Differential Equations: Analytical Solutions / 2.36
- 2.54. Ordinary Differential Equations: Approximate Solutions / 2.40
- 2.55. Partial Differential Equations / 2.45

Part 6. Statistics

- 2.56. Introduction / 2.52
- 2.57. Averages / 2.52
- 2.58. Dispersion / 2.53
- 2.59. Skewness / 2.54
- 2.60. Combinations and Permutations / 2.55
- 2.61. Regression and Correlation / 2.56
- 2.62. Probability / 2.58
- 2.63. Probability Distributions / 2.59
- 2.64. Sampling / 2.63
- 2.65. Tests of Significance / 2.65

Part 7. SI Units

- 2.66. Derived Units / 2.69
- 2.67. Gravitational and Absolute Systems / 2.69
- 2.68. Expressing Magnitudes of SI Units / 2.70
- 2.69. Rules for Use of SI Units and the Decimal Multiples and Submultiples / 2.70
- 2.70. SI Quantities, Units, and Symbols / 2.71

Part 8. Conversion of Existing Imperial Terms**Part 9. Abbreviations****Part 10. Physical and Chemical Constants**

- 2.71. Atomic Number / 2.95
- 2.72. Atomic Weight / 2.95
- 2.73. Density / 2.95
- 2.74. Melting Point / 2.95
- 2.75. Linear Coefficient of Expansion / 2.95
- 2.76. Heat Conductivity / 2.101
- 2.77. Electrical Resistivity / 2.101

Section 3. Mechanical Engineering Principles**3.1****Part 1. Statics of Rigid Bodies****Part 2. Strength of Materials****Part 3. Dynamics of Rigid Bodies**

- 3.1. Basic Definitions / 3.7
- 3.2. Linear and Angular Motion in Two Dimensions / 3.9
- 3.3. Circular Motion / 3.11
- 3.4. Linear and Angular Motion in Three Dimensions / 3.12
- 3.5. Balancing / 3.14
- 3.6. Balancing of Rotating Masses / 3.14

Part 4. Vibrations

- 3.7. Single-Degree-of-Freedom Systems / 3.18
- 3.8. Multi-Degree-of-Freedom Systems / 3.29
- 3.9. Random Vibrations / 3.31

Part 5. Mechanics of Fluids

- 3.10. Introduction / 3.39
- 3.11. Fluid Statics / 3.39
- 3.12. Fluid Flow / 3.43
- 3.13. Flow Measurement / 3.52
- 3.14. Boundary Layer Flow / 3.54
- 3.15. Pressure Transients / 3.58
- 3.16. Gas Flow / 3.60
- 3.17. Ideal Fluid Flow / 3.65
- 3.18. Conclusion / 3.69

Part 6. Principles of Thermodynamics

- 3.19. Introduction / 3.70
- 3.20. The Laws of Thermodynamics / 3.70
- 3.21. Thermoeconomics / 3.72
- 3.22. Work, Heat, Property Values, Process Laws and Combustion / 3.73
- 3.23. Cycle Analysis / 3.74

Part 7. Heat Transfer

- 3.24. Introduction / 3.80
- 3.25. Basic Principles of Heat Transfer / 3.80
- 3.26. Analysis of Heat Transfer / 3.87
- 3.27. Use of Computers / 3.98
- 3.28. Heat Transfer: Nomenclature / 3.99

Section 4. Electrical and Electronic Principles**4.1**

- 4.1. Basic Electrical Technology / 4.1
- 4.2. Electrical Machines / 4.30
- 4.3. Analog and Digital Electronics Theory / 4.69
- 4.4. Electrical Safety / 4.114

Section 5. Computing**5.1**

- 5.1. Introduction / 5.1
- 5.2. Generations of Digital Computers / 5.1
- 5.3. Digital Computer Systems / 5.3
- 5.4. Categories of Computer Systems / 5.5
- 5.5. Central Processor Unit / 5.7
- 5.6. Memory / 5.14
- 5.7. Peripherals / 5.22
- 5.8. Output Devices / 5.23
- 5.9. Terminals / 5.24
- 5.10. Printers and Plotters / 5.25
- 5.11. Direct Input / 5.28
- 5.12. Secondary Storage / 5.29
- 5.13. Digital and Analog Input/Output / 5.35
- 5.14. Data Communications / 5.37
- 5.15. Computer Networks / 5.50
- 5.16. Internet / 5.58
- 5.17. Software / 5.60
- 5.18. Database Management / 5.66
- 5.19. Language Translators / 5.69
- 5.20. Languages / 5.71

Section 6. Microprocessors, Instrumentation, and Control**6.1****Part 1. Summary of Number Systems**

- 6.1. ASCII Code / 6.3
- 6.2. Gray Code / 6.4

Part 2. Microprocessors

- 6.3. System Architecture / 6.5
- 6.4. Bus Structure / 6.6
- 6.5. Memory Devices / 6.6
- 6.6. Input/Output (I/O) Structure / 6.7
- 6.7. Memory Map / 6.9

Part 3. Communication Standards

- 6.8. Serial Communication / 6.11
- 6.9. Parallel Communication / 6.12

Part 4. Interfacing of Computers to Systems

- 6.10. Digital Interfacing / 6.14
- 6.11. Controller Output Interface Hardware / 6.16
- 6.12. Analog Interfacing / 6.21
- 6.13. Multiplexing / 6.26
- 6.14. Machine Tool Interfaces / 6.28

- 6.15. Robot Control Interfaces / 6.29
- 6.16. Signal Conditioning / 6.31
- 6.17. Analog and Digital Filtering / 6.34

Part 5. Instrumentation

- 6.18. Introduction / 6.37
- 6.19. Dimensional/Geometrical Measurements / 6.40
- 6.20. Volume and Level / 6.48
- 6.21. Measurement of Vibration / 6.50
- 6.22. Force/Weight Measurement / 6.51
- 6.23. Pressure / 6.53
- 6.24. Flow / 6.55
- 6.25. Temperature Measurement / 6.59
- 6.26. Bar Code Readers / 6.67

Part 6. Classical Control Theory and Practice

- 6.27. Introduction / 6.69
- 6.28. Mathematical Models of Systems—Time Domain Analysis / 6.75
- 6.29. Laplace Notation for Differential Equations—Frequency-Domain Analysis / 6.80
- 6.30. Stability Criteria / 6.83
- 6.31. Control Strategies / 6.89

Part 7. Microprocessor-Based Control

- 6.32. Direct Digital Control / 6.109
- 6.33. Hardware Requirements / 6.110
- 6.34. Software Considerations / 6.111
- 6.35. Sampling Frequency in Digital Control Loops / 6.114
- 6.36. PID Digital Control Algorithm / 6.115
- 6.37. Speed Control / 6.117
- 6.38. The PC as a Controller / 6.119

Part 8. Programmable Logic Controllers

- 6.39. The PLC in Automation Systems / 6.122
- 6.40. The PLC Versus the Microcomputer / 6.123
- 6.41. Ladder Logic Programming / 6.125
- 6.42. Controlling Pneumatic and Hydraulic Systems / 6.129
- 6.43. Safety / 6.131
- 6.44. Networking of PLCs / 6.131

Part 9. The z-Transform

- 6.45. Representation of Discretely Sampled Data / 6.134
- 6.46. The z-Transform of a Closed-Loop System / 6.138
- 6.47. Proportional Control Using Digital Techniques / 6.141
- 6.48. The z-Transform for a PID Controller / 6.142
- 6.49. A P + I Strategy Using Digital Techniques / 6.143
- 6.50. Stability in Discrete Time Systems / 6.145

Part 10. State Variable Techniques

- 6.51. State Variable Representation of Systems / 6.146
- 6.52. Application to a First-Order System with A P + I Controller / 6.150
- 6.53. Application to a Second-Order System with A P + I Controller / 6.151
- 6.54. Nonlinear System Elements (Method of Isoclines) / 6.153
- 6.55. Sampled-Data Systems / 6.161
- 6.56. State Variable Transformations / 6.163
- 6.57. The State of Transition Matrix / 6.166

Section 7. Aeronautical Propulsion**7.1**

- 7.1. Newton and Propulsion / 7.1
- 7.2. Turbojets and Propellers / 7.2
- 7.3. Thrust Equation / 7.3
- 7.4. Engine Cycles / 7.4
- 7.5. Gas Turbine Engines / 7.7
- 7.6. Ideal Engine Cycle Analysis / 7.7
- 7.7. Goals of Cycle Analysis / 7.9
- 7.8. General Procedure for Cycle Analysis / 7.10
- 7.9. The Turbojet / 7.12
- 7.10. The Turbofan / 7.16
- 7.11. The Turboprop / 7.18
- 7.12. Gas Turbine Component Technology / 7.21
- 7.13. Real Gas Properties / 7.28
- 7.14. Ramjets and Scramjets / 7.28
- 7.15. Reciprocating Engines / 7.33
- 7.16. Aircraft Engine Emissions and Fuels / 7.37
- 7.17. Engine Noise / 7.39

Section 8. Rockets and Launch Vehicles**8.1**

- 8.1. Rocket Science / 8.1
- 8.2. Propulsion Systems / 8.22
- 8.3. Launch Vehicles / 8.43

Section 9. Aerospace Structures**9.1****Part 1. Aircraft Loadings****Part 2. Properties of Materials**

- 9.1. Metals / 9.6
- 9.2. Composites / 9.12
- 9.3. Smart Materials / 9.13

Part 3. Structural Considerations

- 9.4. Structural Analysis / 9.15
- 9.5. Finite Element Analysis / 9.17
- 9.6. Beams / 9.19
- 9.7. Tubes / 9.24
- 9.8. Plates and Shells / 9.26
- 9.9. Real Structures / 9.31
- 9.10. Stress Concentrations / 9.38
- 9.11. Composite Structures / 9.39
- 9.12. Structural Tests / 9.41

Part 4. Structural Dynamics

- 9.13. Introduction / 9.44
- 9.14. Multiple Degree of Freedom Vibration / 9.44
- 9.15. MDOF Free Vibration—Lumped Mass Models / 9.44
- 9.16. Setting Up Equations of Motion—Finite-Element Approach / 9.46
- 9.17. Global Stiffness and Mass Matrices—Element Assembly / 9.47
- 9.18. MDOF Vibration—Setting Up Equations of Motion—Rayleigh-Ritz Method / 9.48

- 9.19. Aeroelasticity / 9.56
- 9.20. Noise / 9.61
- 9.21. Helicopters / 9.61
- 9.22. Aircraft Airworthiness Certification / 9.62
- 9.23. Aeroelastic Design / 9.64

Part 5. Spacecraft Structures

- 9.24. Role of Spacecraft Structures and Various Interfaces / 9.65
- 9.25. Mechanical Requirements / 9.67
- 9.26. Space Mission Environment and Mechanical Loads / 9.68
- 9.27. Project Overview: Successive Designs and Iterative Verification of Structural Requirements / 9.70
- 9.28. Analytical Evaluations / 9.71
- 9.29. Test Verification, Qualification, and Flight Acceptance / 9.72
- 9.30. Satellite Qualification and Flight Acceptance / 9.74
- 9.31. Materials and Processes / 9.75
- 9.32. Manufacturing of Spacecraft Structures / 9.77

Section 10. Aerodynamics, Performance and Stability and Control 10.1

- 10.1. Introduction / 10.1

Part 1. Aerodynamics

- 10.2. Airfoil Geometric and Aerodynamic Definitions / 10.5
- 10.3. Wing Geometric and Aerodynamic Definitions / 10.13
- 10.4. Fundamentals of Vector Fluid Dynamics / 10.16
- 10.5. Fundamentals of Potential Flow / 10.24
- 10.6. Elementary Boundary Layer Flow / 10.34
- 10.7. Incompressible Flow over Airfoils / 10.42
- 10.8. Incompressible Flow over Finite Wings / 10.63
- 10.9. Shock Wave Relationships / 10.76
- 10.10. Compressible Flow over Airfoils / 10.85
- 10.11. Compressible Flow over Finite Wings / 10.94

Part 2. Airplane Performance

- 10.12. Standard Atmosphere and Height Measurement / 10.108
- 10.13. Airspeed and Airspeed Measurement / 10.119
- 10.14. Drag and Drag Power (Power Required) / 10.122
- 10.15. Engine (Powerplant) Performance / 10.127
- 10.16. Level Flight Performance / 10.134
- 10.17. Climbing and Descending Flight / 10.138
- 10.18. Turning Performance / 10.146
- 10.19. Stall and Spin / 10.148
- 10.20. Range and Endurance / 10.150
- 10.21. Takeoff and Landing Performance / 10.156
- 10.22. Airplane Operations / 10.163

Part 3. Aircraft Stability and Control

- 10.23. Mathematical Modeling and Simulation of Fixed Wing Aircraft / 10.172
- 10.24. Development of the Linearized Equations of Motion / 10.179
- 10.25. Calculation of Aerodynamic Derivatives / 10.188
- 10.26. Aircraft Dynamic Stability / 10.191
- 10.27. Aircraft Response to Controls and Atmospheric Disturbances / 10.196

Section 11. Avionics and Astrionics**11.1****Part 1. The Electromagnetic Spectrum**

- 11.1. Radiowaves in the Vacuum / 11.2
- 11.2. Antennas and Power Budget of a Radio Link / 11.3
- 11.3. Radiowave Propagation in the Terrestrial Environment / 11.4
- 11.4. Management of the Electromagnetic Spectrum / 11.7

Part 2. The Spacecraft Environment

- 11.5. Introduction to the Space Environment / 11.9
- 11.6. Effects of the Space Environment on Spacecraft, Launchers and Airplanes / 11.10
- 11.7. The Energetic Charged Particle Environment / 11.13

Part 3. Aircraft Environment

- 11.8. Typical Flight Profile for Commercial Airplanes / 11.21
- 11.9. The Atmosphere / 11.23
- 11.10. Other Atmospheric Hazards / 11.31
- 11.11. The Ionosphere / 11.35

Part 4. Electromagnetic Compatibility

- 11.12. Introduction / 11.36
- 11.13. Background of EM Coupling / 11.37
- 11.14. EM Environment and EMC Standards / 11.40
- 11.15. EMC Tools / 11.42
- 11.16. Engineering Method / 11.45
- 11.17. Conclusion / 11.47

Part 5. Introduction to Radar

- 11.18. Historical Background / 11.49
- 11.19. Basic Principles / 11.49
- 11.20. Trends in Radar Technology / 11.55
- 11.21. Radar Applications to Aeronautics / 11.57
- 11.22. Overview of Military Requirements and Specific Developments / 11.59
- 11.23. Overview of Radar Applications to Space / 11.60

Part 6. Optical Fibers and Lasers

- 11.24. Optical Fiber Theory and Applications / 11.62
- 11.25. Lasers / 11.72
- 11.26. Specific Laser Systems / 11.81

Part 7. Photovoltaics

- 11.27. Solar Radiation / 11.86
- 11.28. Photovoltaic Cell / 11.86
- 11.29. The Solar Array / 11.88

Part 8. Aircraft Flight Control Systems

- 11.30. Foreword / 11.91
- 11.31. Flight Control Objectives and Principles / 11.91
- 11.32. Flight Control Systems Design / 11.97
- 11.33. Airbus Fly-by-Wire: An Example of Modern Flight Control / 11.105
- 11.34. Some Control Challenges / 11.118
- 11.35. Conclusion / 11.120