

*Introduction to*

# *Flight*

*Eighth Edition*



John D. Anderson Jr.



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# Introduction to Flight

**Eighth Edition**

**John D. Anderson, Jr.**

*Curator for Aerodynamics, National Air and Space Museum  
Smithsonian Institution*

**Professor Emeritus**

*University of Maryland*





## INTRODUCTION TO FLIGHT, EIGHTH EDITION

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This book is printed on acid-free paper.

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

ISBN 978-0-07-802767-3

MHID 0-07-802767-5

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Design: *Studio Montage*  
Content Licensing Specialist: *Ann Marie Jannette*  
Cover Images: *Front Cover: First Flight: Library of Congress Prints & Photographs Division; X-48B: NASA Dryden Flight Research Center Photo Collection; Spitfire: RAF Museum of London. X-15 hypersonic: Courtesy of the Air Force Test Center History Office. Back Cover: Wright Brothers: Library of Congress Prints & Photographs Division.*  
Compositor: *MPS Limited*  
Typeface: *10.5/12 Times LTStd*  
Printer: *R. R. Donnelley*

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### Library of Congress Cataloging-in-Publication Data

Anderson, John D., Jr. (John David), 1937-  
Introduction to flight / John D. Anderson, Jr., curator for aerodynamics,  
National Air and Space Museum, Smithsonian Institution, professor emeritus,  
University of Maryland. -- Eighth edition.  
pages cm  
Includes bibliographical references and index.  
ISBN 978-0-07-802767-3 (alk. paper) -- ISBN 0-07-802767-5 (alk. paper) 1.  
Aerodynamics. 2. Airplanes--Design and construction. 3. Space flight. I.  
Title.  
TL570.A68 2014  
629.1--dc23

2014041283

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw-Hill Education, and McGraw-Hill Education does not guarantee the accuracy of the information presented at these sites.

## ABOUT THE AUTHOR

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**John D. Anderson, Jr.**, was born in Lancaster, Pennsylvania, on October 1, 1937. He attended the University of Florida, graduating in 1959 with high honors and a Bachelor of Aeronautical Engineering degree. From 1959 to 1962 he was a lieutenant and task scientist at the Aerospace Research Laboratory at Wright-Patterson Air Force Base. From 1962 to 1966 he attended The Ohio State University under National Science Foundation and NASA Fellowships, graduating with a PhD in Aeronautical and Astronautical Engineering. In 1966 he joined the U.S. Naval Ordnance Laboratory as Chief of the Hypersonic Group. In 1973 he became Chairman of the Department of Aerospace Engineering at the University of Maryland, and from 1980 to his retirement in 1999 he was Professor of Aerospace Engineering at Maryland. In 1982 he was designated a Distinguished Scholar/Teacher by the university. During 1986–1987, while on sabbatical from the university, Dr. Anderson occupied the Charles Lindbergh Chair at the National Air and Space Museum of the Smithsonian Institution. In addition to his appointment in aerospace engineering, in 1993 he was elected to the faculty of the Committee on the History and Philosophy of Science at Maryland, and an affiliate faculty member in the Department of History. Since 1999, he is Professor Emeritus of Aerospace Engineering, and Glenn L. Martin Institute Professor of Engineering at Maryland. Also since 1999, he is the Curator of Aerodynamics at the National Air and Space Museum of the Smithsonian Institution.



Dr. Anderson has published eleven books: *Gasdynamic Lasers: An Introduction*, Academic Press (1976), *A History of Aerodynamics and Its Impact on Flying Machines*, Cambridge University Press (1997), *The Airplane: A History of Its Technology*, American Institute of Aeronautics and Astronautics (2003), *Inventing Flight*, Johns Hopkins University Press (2004), *X-15: The World's Fastest Rocket Plane and the Pilots Who Ushered in the Space Age* (with Richard Passman), Zenith Press (2014), and with McGraw-Hill, *Introduction to Flight*, 7th edition (2012), *Modern Compressible Flow*, 3rd Edition (2003), *Fundamentals of Aerodynamics*, 5th edition (2011), *Hypersonic and High Temperature Gas Dynamics* (1989), *Computational Fluid Dynamics: The Basics with Applications* (1995), and *Aircraft Performance and Design* (1999). He is the author of more than 120 papers on radiative gasdynamics, entry aerothermodynamics, gas dynamic and chemical lasers, computational fluid dynamics, applied aerodynamics, hypersonic flow, and the history of aerodynamics. Dr. Anderson is in *Who's Who in America* and is a member of the National Academy of Engineering, an Honorary Fellow of the American Institute of Aeronautics and Astronautics, and Fellow of the Royal Aeronautical Society. He is also a Fellow of the Washington Academy of Sciences and a member of Tau Beta Pi, Sigma Tau, Phi Kappa Phi, Phi Eta Sigma, The American Society for Engineering Education (ASEE), the Society for the History of Technology, and the History of Science Society. He has received the Lee Atwood Award for excellence in Aerospace Engineering Education from the AIAA and the ASEE, the Pendray Award for Aerospace Literature from the AIAA, the von Karman Lectureship from the AIAA, the Gardner-Lasser History Book Award from the AIAA, and the Hypersonic Systems Award from the AIAA.



**To Sarah-Allen, Katherine, and Elizabeth Anderson  
For all their love and understanding,  
and to my two lovely granddaughters, Keegan and Tierney Glabus**

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JOHN D. ANDERSON, JR.



# CONTENTS

About the Author	iii		
Preface to the Eighth Edition	xiii		
Preface to the First Edition	xvii		
<b>Chapter 1</b>			
<b>The First Aeronautical Engineers 1</b>			
1.1	Introduction	1	
1.2	Very Early Developments	3	
1.3	Sir George Cayley (1773–1857)— The True Inventor of the Airplane	6	
1.4	The Interregnum—From 1853 to 1891	13	
1.5	Otto Lilienthal (1848–1896)—The Glider Man	17	
1.6	Percy Pilcher (1867–1899)—Extending The Glider Tradition	20	
1.7	Aeronautics Comes to America	21	
1.8	Wilbur (1867–1912) and Orville (1871– 1948) Wright—Inventors of the First Practical Airplane	26	
1.9	The Aeronautical Triangle—Langley, The Wrights, and Glenn Curtiss	35	
1.10	The Problem of Propulsion	44	
1.11	Faster and Higher	45	
1.12	Summary and Review	48	
	Bibliography	51	
<b>Chapter 2</b>			
<b>Fundamental Thoughts 53</b>			
2.1	Fundamental Physical Quantities of a Flowing Gas	57	
	2.1.1 Pressure	57	
	2.1.2 Density	58	
	2.1.3 Temperature	59	
	2.1.4 Flow Velocity and Streamlines	60	
2.2	The Source of All Aerodynamic Forces	62	
2.3	Equation of State for a Perfect Gas	64	
2.4	Discussion of Units	66	
2.5	Specific Volume	71	
2.6	Anatomy of the Airplane	82	
2.7	Anatomy of a Space Vehicle	92	
2.8	Historical Note: The NACA and NASA	101	
2.9	Summary and Review	104	
	Bibliography	105	
	Problems	106	
<b>Chapter 3</b>			
<b>The Standard Atmosphere 110</b>			
3.1	Definition of Altitude	112	
3.2	Hydrostatic Equation	113	
3.3	Relation Between Geopotential and Geometric Altitudes	115	
3.4	Definition of the Standard Atmosphere	116	
3.5	Pressure, Temperature, and Density Altitudes	125	
3.6	Historical Note: The Standard Atmosphere	128	
3.7	Summary and Review	130	
	Bibliography	132	
	Problems	132	



**Chapter 4****Basic Aerodynamics 134**

- 4.1 Continuity Equation 138
- 4.2 Incompressible and Compressible Flow 139
- 4.3 Momentum Equation 142
- 4.4 A Comment 146
- 4.5 Elementary Thermodynamics 153
- 4.6 Isentropic Flow 160
- 4.7 Energy Equation 166
- 4.8 Summary of Equations 173
- 4.9 Speed of Sound 174
- 4.10 Low-Speed Subsonic Wind Tunnels 182
- 4.11 Measurement of Airspeed 188
  - 4.11.1 *Incompressible Flow* 191
  - 4.11.2 *Subsonic Compressible Flow* 197
  - 4.11.3 *Supersonic Flow* 205
  - 4.11.4 *Summary* 210
- 4.12 Some Additional Considerations 210
  - 4.12.1 *More about Compressible Flow* 211
  - 4.12.2 *More about Equivalent Airspeed* 213
- 4.13 Supersonic Wind Tunnels and Rocket Engines 214
- 4.14 Discussion of Compressibility 226
- 4.15 Introduction to Viscous Flow 227
- 4.16 Results for a Laminar Boundary Layer 236
- 4.17 Results for a Turbulent Boundary Layer 241
- 4.18 Compressibility Effects on Skin Friction 244
- 4.19 Transition 247
- 4.20 Flow Separation 250
- 4.21 Summary of Viscous Effects on Drag 255
- 4.22 Historical Note: Bernoulli and Euler 257
- 4.23 Historical Note: The Pitot Tube 258

- 4.24 Historical Note: The First Wind Tunnels 261
- 4.25 Historical Note: Osborne Reynolds and his Number 267
- 4.26 Historical Note: Prandtl and the Development of the Boundary Layer Concept 271
- 4.27 Summary and Review 274
  - Bibliography 278
  - Problems 279

**Chapter 5****Airfoils, Wings, and Other Aerodynamic Shapes 288**

- 5.1 Introduction 288
- 5.2 Airfoil Nomenclature 290
- 5.3 Lift, Drag, and Moment Coefficients 294
- 5.4 Airfoil Data 300
- 5.5 Infinite versus Finite Wings 315
- 5.6 Pressure Coefficient 316
- 5.7 Obtaining Lift Coefficient from  $C_p$  322
- 5.8 Compressibility Correction for Lift Coefficient 326
- 5.9 Critical Mach Number and Critical Pressure Coefficient 327
- 5.10 Drag-Divergence Mach Number 339
- 5.11 Wave Drag (At Supersonic Speeds) 347
- 5.12 Summary of Airfoil Drag 357
- 5.13 Finite Wings 359
- 5.14 Calculation of Induced Drag 363
- 5.15 Change in the Lift Slope 372
- 5.16 Swept Wings 381
- 5.17 Flaps—A Mechanism for High Lift 394
- 5.18 Aerodynamics of Cylinders and Spheres 400
- 5.19 How Lift is Produced—Some Alternative Explanations 405

- 5.20** Historical Note: Airfoils and Wings 415
- 5.20.1 *The Wright Brothers* 416
  - 5.20.2 *British and U.S. Airfoils (1910–1920)* 417
  - 5.20.3 *1920–1930* 418
  - 5.20.4 *Early NACA Four-Digit Airfoils* 418
  - 5.20.5 *Later NACA Airfoils* 419
  - 5.20.6 *Modern Airfoil Work* 419
  - 5.20.7 *Finite Wings* 420
- 5.21** Historical Note: Ernst Mach and his Number 422
- 5.22** Historical Note: The First Manned Supersonic Flight 426
- 5.23** Historical Note: The X-15—First Manned Hypersonic Airplane and Stepping-Stone to the Space Shuttle 430
- 5.24** Summary and Review 432
- Bibliography 434
  - Problems 435
- Chapter 6**
- Elements of Airplane Performance** 441
- 6.1** Introduction: The Drag Polar 441
- 6.2** Equations of Motion 448
- 6.3** Thrust Required for Level, Unaccelerated Flight 450
- 6.4** Thrust Available and Maximum Velocity 458
- 6.5** Power Required for Level, Unaccelerated Flight 461
- 6.6** Power Available and Maximum Velocity 466
- 6.6.1 *Reciprocating Engine–Propeller Combination* 466
  - 6.6.2 *Jet Engine* 468
- 6.7** Altitude Effects on Power Required and Available 470
- 6.8** Rate of Climb 479
- 6.9** Gliding Flight 489
- 6.10** Absolute and Service Ceilings 493
- 6.11** Time to Climb 499
- 6.12** Range and Endurance: Propeller-Driven Airplane 500
- 6.12.1 *Physical Considerations* 501
  - 6.12.2 *Quantitative Formulation* 502
  - 6.12.3 *Breguet Formulas (Propeller-Driven Airplane)* 504
- 6.13** Range and Endurance: Jet Airplane 508
- 6.13.1 *Physical Considerations* 509
  - 6.13.2 *Quantitative Formulation* 510
- 6.14** Relations Between  $C_{D,0}$  and  $C_{D,i}$  514
- 6.15** Takeoff Performance 522
- 6.16** Landing Performance 528
- 6.17** Turning Flight and the  $V-n$  Diagram 531
- 6.18** Accelerated Rate of Climb (Energy Method) 540
- 6.19** Special Considerations for Supersonic Airplanes 547
- 6.20** Uninhabited Aerial Vehicles (UAVs) 550
- 6.21** Micro Air Vehicles 560
- 6.22** Quest for Aerodynamic Efficiency 563
- 6.22.1 *Measure of Aerodynamic Efficiency* 563
  - 6.22.2 *What Dictates the Value of L/D?* 564
  - 6.22.3 *Sources of Aerodynamic Drag; Drag Reduction* 564
  - 6.22.4 *Some Innovative Aircraft Configurations for High L/D* 569
- 6.23** A Comment 571
- 6.24** Historical Note: Drag Reduction—The NACA Cowling and the Fillet 572
- 6.25** Historical Note: Early Predictions of Airplane Performance 576
- 6.26** Historical Note: Breguet and the Range Formula 578
- 6.27** Historical Note: Aircraft Design—Evolution and Revolution 579

- 6.28** Summary and Review 584
- Bibliography 588
- Problems 588

## Chapter 7

### **Principles of Stability and Control** 594

- 7.1** Introduction 594
- 7.2** Definition of Stability and Control 600
  - 7.2.1 *Static Stability* 601
  - 7.2.2 *Dynamic Stability* 602
  - 7.2.3 *Control* 604
  - 7.2.4 *Partial Derivative* 604
- 7.3** Moments on the Airplane 605
- 7.4** Absolute Angle of Attack 606
- 7.5** Criteria for Longitudinal Static Stability 608
- 7.6** Quantitative Discussion: Contribution of the Wing to  $M_{cg}$  613
- 7.7** Contribution of the Tail to  $M_{cg}$  617
- 7.8** Total Pitching Moment About the Center of Gravity 620
- 7.9** Equations for Longitudinal Static Stability 622
- 7.10** Neutral Point 624
- 7.11** Static Margin 625
- 7.12** Concept of Static Longitudinal Control 629
- 7.13** Calculation of Elevator Angle to Trim 634
- 7.14** Stick-Fixed Versus Stick-Free Static Stability 636
- 7.15** Elevator Hinge Moment 637
- 7.16** Stick-Free Longitudinal Static Stability 639
- 7.17** Directional Static Stability 643
- 7.18** Lateral Static Stability 644
- 7.19** A Comment 646
- 7.20** Historical Note: The Wright Brothers Versus the European Philosophy of Stability and Control 647

- 7.21** Historical Note: The Development of Flight Controls 648
- 7.22** Historical Note: The “Tuck-Under” Problem 650
- 7.23** Summary and Review 651
  - Bibliography 653
  - Problems 653

## Chapter 8

### **Space Flight (Astronautics)** 655

- 8.1** Introduction 655
- 8.2** Differential Equations 662
- 8.3** Lagrange’s Equation 663
- 8.4** Orbit Equation 666
  - 8.4.1 *Force and Energy* 666
  - 8.4.2 *Equation of Motion* 668
- 8.5** Space Vehicle Trajectories—Some Basic Aspects 672
- 8.6** Kepler’s Laws 679
- 8.7** An Application: The Voyager Spacecraft—Their Design, Flight Trajectories, and Historical Significance 683
- 8.8** Introduction to Earth and Planetary Entry 687
- 8.9** Exponential Atmosphere 690
- 8.10** General Equations of Motion for Atmospheric Entry 690
- 8.11** Application to Ballistic Entry 694
- 8.12** Entry Heating 700
- 8.13** Lifting Entry, with Application to the Space Shuttle 708
- 8.14** Historical Note: Kepler 712
- 8.15** Historical Note: Newton and the Law of Gravitation 714
- 8.16** Historical Note: Lagrange 716
- 8.17** Historical Note: Unmanned Space Flight 716
- 8.18** Historical Note: Manned Space Flight 721

- 8.19 Summary and Review 723
- Bibliography 725
- Problems 725

## Chapter 9

### Propulsion 728

- 9.1 Introduction 728
- 9.2 Propeller 731
- 9.3 Reciprocating Engine 738
- 9.4 Jet Propulsion—The Thrust Equation 749
- 9.5 Turbojet Engine 752
  - 9.5.1 Thrust Buildup for a Turbojet Engine 757
- 9.6 Turbofan Engine 763
- 9.7 Ramjet Engine 765
- 9.8 Rocket Engine 769
- 9.9 Rocket Propellants—Some Considerations 776
  - 9.9.1 Liquid Propellants 776
  - 9.9.2 Solid Propellants 779
  - 9.9.3 A Comment 781
- 9.10 Rocket Equation 782
- 9.11 Rocket Staging 783
- 9.12 Quest for Engine Efficiency 787
  - 9.12.1 Propulsive Efficiency 788
  - 9.12.2 The Green Engine 791
- 9.13 Electric Propulsion 792
  - 9.13.1 Electron-Ion Thruster 792
  - 9.13.2 Magnetoplasmadynamic Thruster 793
  - 9.13.3 Arc-Jet Thruster 793
  - 9.13.4 A Comment 794
- 9.14 Historical Note: Early Propeller Development 795
- 9.15 Historical Note: Early Development of the Internal Combustion Engine for Aviation 797
- 9.16 Historical Note: Inventors of Early Jet Engines 800

- 9.17 Historical Note: Early History of Rocket Engines 803
- 9.18 Summary and Review 809
  - Bibliography 810
  - Problems 811

## Chapter 10

### Hypersonic Vehicles 815

- 10.1 Introduction 815
- 10.2 Physical Aspects of Hypersonic Flow 819
  - 10.2.1 Thin Shock Layers 819
  - 10.2.2 Entropy Layer 820
  - 10.2.3 Viscous Interaction 821
  - 10.2.4 High-Temperature Effects 822
  - 10.2.5 Low-Density Flow 823
  - 10.2.6 Recapitulation 827
- 10.3 Newtonian Law for Hypersonic Flow 827
- 10.4 Some Comments About Hypersonic-Airplanes 833
- 10.5 Summary and Review 844
  - Bibliography 845
  - Problems 845

### Appendix A: Standard Atmosphere, SI Units 847

### Appendix B: Standard Atmosphere, English Engineering Units 857


### Appendix C: Symbols and Conversion Factors 865


### Appendix D: Airfoil Data 866

### Answer Key 895

### Index 899

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## PREFACE TO THE EIGHTH EDITION

The purpose of the present edition is the same as that of the first seven: to present the basic fundamentals of aerospace engineering at the introductory level in the clearest, simplest, and most motivating way possible. Because the book is meant to be enjoyed as well as understood, I have made every effort to ensure a clear and readable text. The choice of subject matter and its organization, the order in which topics are introduced, and how these ideas are explained have been carefully planned with the uninitiated reader in mind. I simply put myself in the shoes of the reader who has no knowledge of the subject matter, ask myself how I would want to hear about the subject, and then start “talking” to the reader. Because the book is intended as a self-contained text at the first- and second-year levels, I avoid tedious details and massive “handbook” data. Instead, I introduce and discuss fundamental concepts in a manner that is as straightforward and clean-cut as possible, knowing that the book has also found favor with those who wish to learn something about this subject outside the classroom.

The overwhelmingly favorable response to the earlier editions from students, teachers, and practicing professionals both here and abroad is a source of gratification. Particularly pleasing is the fact that those using the book have enjoyed reading its treatment of the fascinating, challenging, and sometimes awesome discipline of aerospace engineering.

Thanks to this response, much of the content of the seventh edition has been carried over into the eight edition. A hallmark of this book is the use of specially designed devices to enhance the reader’s understanding of the material. In particular, these features are carried over from the seventh edition:

1. *Road maps* placed at the beginning of each chapter help guide the reader through the logical flow of the material.
2. *Design boxes* discuss interesting and important applications of the fundamental material; this material is literally set apart in boxes.
3. *Preview boxes* at the chapter beginnings give the reader insight into what each chapter is about and why the material is important. I intend the preview boxes to be motivational, to make the reader interested and curious enough to pay close attention to the content of the chapter. These preview boxes are written in an informal manner to help turn the reader on to the content. In these preview boxes, I am unabashedly admitting to providing fun for the readers.
4. *Summary and Review sections* at the end of the chapters contain the important ideas and concepts presented in each chapter, first without

equations, to remind readers about the physical aspects of the material and to provide a focused intellectual background for the equations that are then summarized at the end of the section.

In the same spirit, the eighth edition contains new material intended to enhance the education and interest of the reader:

1. Two new sections, Section 6.22, “Quest for Aerodynamic Efficiency,” and Section 9.12, “Quest for Engine Efficiency,” are added to provide a look into the future for new, efficient aircraft, with implications for a future “green airplane.”
2. A new Section 8.7, “An Application: The Voyager Spacecraft—Their Design, Flight Trajectories, and Historical Significance,” has been added to highlight these important space vehicles and their missions.
3. Some additional worked examples are supplied to further help readers to understand how to use what they have been reading.
4. Some additional homework problems grace the end of some chapters. An answer key is placed at the end of the book for selected homework problems.

All told, the new material represents a meaningful enhancement of *Introduction to Flight*.

To allow space for this new material in the eighth edition, without inordinately increasing the length of the book, some text material originally in Chs. 6, 8, and 9 has been removed from the eighth edition and placed on the book’s website.

At the University of Maryland this text is used for an introductory course for sophomores in aerospace engineering. It leads directly into a second book by the author, *Fundamentals of Aerodynamics*, 5th edition (McGraw-Hill, 2011), which is used in a two-semester junior-senior aerodynamics course. This, in turn, feeds into a third text, *Modern Compressible Flow: With Historical Perspective*, 3rd edition (McGraw-Hill, 2003), used in a course for advanced undergraduates and first-year graduate students. The complete triad is intended to give students a reasonable technical and historical perspective on aerospace engineering in general and aerodynamics in particular.

I am very grateful to Mrs. Susan Cunningham, who did such an excellent job of typing the manuscript. I am fortunate to have such dedicated and professional help from one of the best scientific typists in the world. My gratitude also goes out to my wife of 54 years, Sarah-Allen, who has helped to motivate and expedite the effort that has gone into this book. Finally, special thanks go to my very special editor, Lorraine Buczek at McGraw-Hill, whose dedication and hard work has been extremely helpful in getting this edition finished and published, and who has become a very special friend over the years. Lorraine and I form a great McGraw-Hill team.

Finally, emphasizing that the study, understanding, and practice of the profession of aerospace engineering is one of the most gratifying of human endeavors and that my purpose is to instill a sense of enthusiasm, dedication, and love of the subject, let me simply say to the reader: read, learn, and enjoy.

**John D. Anderson, Jr.**

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## **PREFACE TO THE FIRST EDITION**

**T**his book is an introduction to aerospace engineering from both the technological and historical points of view. It is written to appeal to several groups of people: (1) students of aerospace engineering in their freshman or sophomore years in college who are looking for a comprehensive introduction to their profession; (2) advanced high school seniors who want to learn what aerospace engineering is all about; (3) college undergraduate and graduate students who want to obtain a wider perspective on the glories, the intellectual demands, and the technical maturity of aerospace engineering; and (4) working engineers who simply want to obtain a firmer grasp on the fundamental concepts and historical traditions that underlie their profession.

As an introduction to aerospace engineering, this book is unique in at least three ways. First, the vast majority of aerospace engineering professionals and students have little knowledge or appreciation of the historical traditions and background associated with the technology that they use almost every day. To fill this vacuum, the present book marbles some history of aerospace engineering into the parallel technical discussions. For example, such questions as who Bernoulli was, where the Pitot tube originated, how wind tunnels evolved, who the first true aeronautical engineers were, and how wings and airfoils developed are answered. The present author feels strongly that such material should be an integral part of the background of all aerospace engineers.

Second, this book incorporates both the SI and the English engineering system of units. Modern students of aerospace engineering must be bilingual—on one hand, they must fully understand and feel comfortable with the SI units—because most modern and all future literature will deal with the SI system; on the other hand, they must be able to read and feel comfortable with the vast bulk of existing literature, which is predominantly in engineering units. In this book the SI system is emphasized, but an honest effort is made to give the reader a feeling for and understanding of both systems. To this end, some example problems are worked out in the SI system and others in the English system.

Third, the author feels that technical books do not have to be dry and sterile in their presentation. Instead the present book is written in a rather informal style. It talks to the reader. Indeed it is intended to be almost a self-teaching, self-pacing vehicle that the reader can use to obtain a fundamental understanding of aerospace engineering.

This book is a product of several years of teaching the introductory course in aerospace engineering at the University of Maryland. Over these

years, students have constantly encouraged the author to write a book about the subject, and their repeated encouragement could not be denied. The present book is dedicated in part to these students.

Writing a book of this magnitude is a total commitment of time and effort for a longer time than the author likes to remember. In this light, this book is dedicated to my wife, Sarah-Allen, and my two daughters, Katherine and Elizabeth, who relinquished untold amounts of time with their husband and father so that these pages could be created. To them I say thank you, and hello again. Also, hidden between the lines but ever-so-much present is Edna Brothers, who typed the manuscript in such a dedicated fashion. In addition, the author wishes to thank Dr. Richard Hallion and Dr. Thomas Crouch, curators of the National Air and Space Museum of the Smithsonian Institution, for their helpful comments on the historical sections of this manuscript, and especially Dick Hallion for opening the vast archives of the museum for the author's historical research. Also, many thanks are due to the reviewers of this manuscript: Professor J. J. Azar of the University of Tulsa, Dr. R. F. Brodsky of Iowa State University, Dr. David Caughey of Sibley School of Mechanical and Aerospace Engineering, and Professor Francis J. Hale of North Carolina State University; their comments have been most constructive, especially those of Dr. Caughey and Professor Hale. Finally, the author wishes to thank his many colleagues in the profession for stimulating discussions about what constitutes an introduction to aerospace engineering. The author hopes that this book is a reasonable answer.

**John D. Anderson, Jr.**

# The First Aeronautical Engineers

Nobody will fly for a thousand years!

*Wilbur Wright, 1901, in a fit of despair*

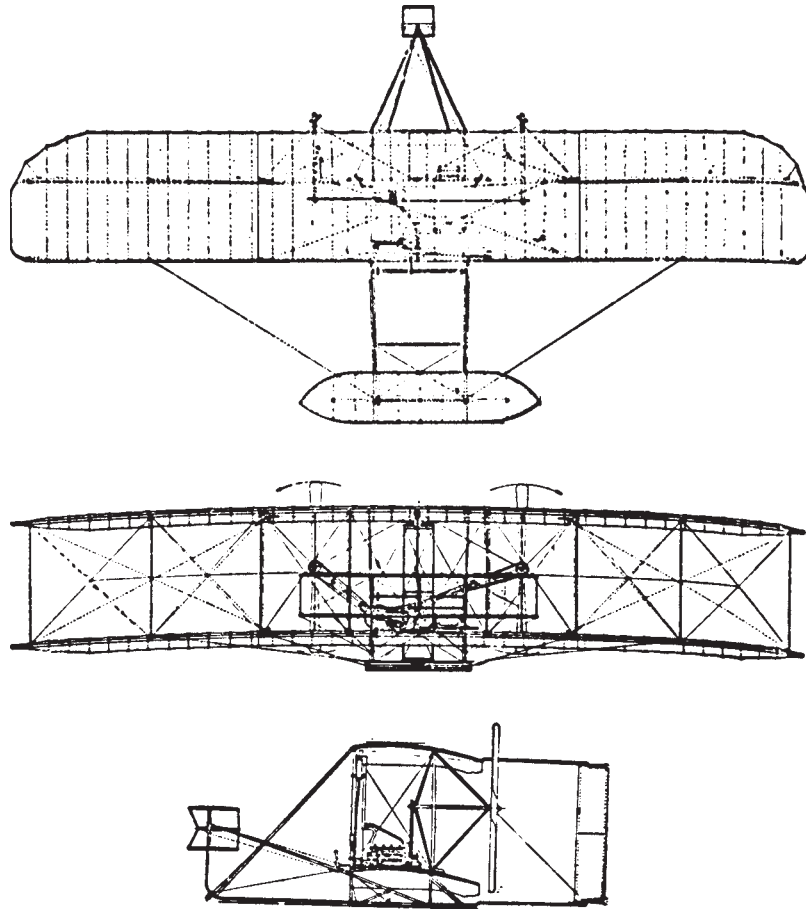
SUCCESS FOUR FLIGHTS THURSDAY MORNING ALL AGAINST TWENTY ONE MILE WIND STARTED FROM LEVEL WITH ENGINE POWER ALONE AVERAGE SPEED THROUGH AIR THIRTY ONE MILES LONGEST 57 SECONDS INFORM PRESS HOME CHRISTMAS.

*ORVILLE WRIGHT*

*A telegram, with the original misprints,  
from Orville Wright to his father,  
December 17, 1903*

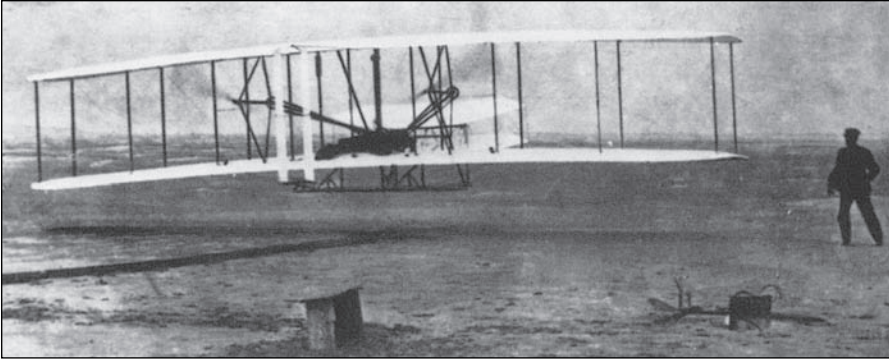
## 1.1 INTRODUCTION

*The scene:* Windswept sand dunes of Kill Devil Hills, 4 mi south of Kitty Hawk, North Carolina. *The time:* About 10:35 AM on Thursday, December 17, 1903. *The characters:* Orville and Wilbur Wright and five local witnesses. *The action:* Poised, ready to make history, is a flimsy, odd-looking machine, made from spruce and cloth in the form of two wings, one placed above the other, a horizontal elevator mounted on struts in front of the wings, and a double vertical rudder behind the wings (see Fig. 1.1). A 12-hp engine is mounted on the top surface of the bottom wing, slightly right of center. To the left of this engine lies a



**Figure 1.1** Three views of the *Wright Flyer I*, 1903.

man—Orville Wright—prone on the bottom wing, facing into the brisk and cold December wind. Behind him rotate two ungainly looking airscrews (propellers), driven by two chain-and-pulley arrangements connected to the same engine. The machine begins to move along a 60-ft launching rail on level ground. Wilbur Wright runs along the right side of the machine, supporting the wing tip so it will not drag the sand. Near the end of the starting rail, the machine lifts into the air; at this moment, John Daniels of the Kill Devil Life Saving Station takes a photograph that preserves for all time the most historic moment in aviation history (see Fig. 1.2). The machine flies unevenly, rising suddenly to about 10 ft, then ducking quickly toward the ground. This type of erratic flight continues for 12 s, when the machine darts to the sand, 120 ft from the point where it lifted from the starting rail. Thus ends a flight that, in Orville Wright's own words, was "the first in the history of the world in which a machine carrying a man



**Figure 1.2** The first heavier-than-air flight in history: the *Wright Flyer I* with Orville Wright at the controls, December 17, 1903.

(Source: *Library of Congress [LC-DIG-ppprs-00626].*)

had raised itself by its own power into the air in full flight, had sailed forward without reduction of speed, and had finally landed at a point as high as that from which it started.”

The machine was the *Wright Flyer I*, which is shown in Figs. 1.1 and 1.2 and which is now preserved for posterity in the Air and Space Museum of the Smithsonian Institution in Washington, District of Columbia. The flight on that cold December 17 was momentous: It brought to a realization the dreams of centuries, and it gave birth to a new way of life. It was the first genuine powered flight of a heavier-than-air machine. With it, and with the further successes to come over the next five years, came the Wright brothers’ clear right to be considered the premier aeronautical engineers of history.

However, contrary to some popular belief, the Wright brothers did not truly *invent* the airplane; rather, they represent the fruition of a century’s worth of prior aeronautical research and development. The time was ripe for the attainment of powered flight at the beginning of the 20th century. The Wright brothers’ ingenuity, dedication, and persistence earned them the distinction of being first. The purpose of this chapter is to look back over the years that led up to successful powered flight and to single out an important few of those inventors and thinkers who can rightfully claim to be the first aeronautical engineers. In this manner, some of the traditions and heritage that underlie modern aerospace engineering will be more appreciated when we develop the technical concepts of flight in subsequent chapters.

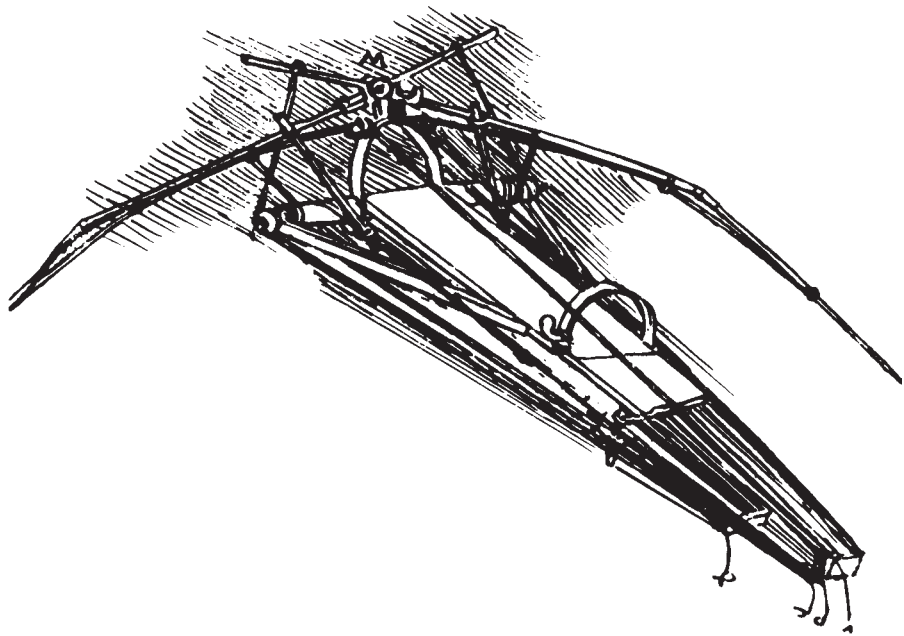
## 1.2 VERY EARLY DEVELOPMENTS

Since the dawn of human intelligence, the idea of flying in the same realm as birds has possessed human minds. Witness the early Greek myth of Daedalus and his son Icarus. Imprisoned on the island of Crete in the Mediterranean Sea, Daedalus is said to have made wings fastened with wax. With these wings, they

both escaped by flying through the air. However, Icarus, against his father's warnings, flew too close to the sun; the wax melted, and Icarus fell to his death in the sea.

All early thinking about human flight centered on the imitation of birds. Various unsung ancient and medieval people fashioned wings and met with sometimes disastrous and always unsuccessful consequences in leaping from towers or roofs, flapping vigorously. In time, the idea of strapping a pair of wings to arms fell out of favor. It was replaced by the concept of wings flapped up and down by various mechanical mechanisms, powered by some type of human arm, leg, or body movement. These machines are called *ornithopters*. Recent historical research has revealed that Leonardo da Vinci was possessed by the idea of human flight and that he designed vast numbers of ornithopters toward the end of the 15th century. In his surviving manuscripts, more than 35,000 words and 500 sketches deal with flight. One of his ornithopter designs is shown in Fig. 1.3, which is an original da Vinci sketch made sometime between 1486 and 1490. It is not known whether da Vinci ever built or tested any of his designs. However, human-powered flight by flapping wings was always doomed to failure. In this sense, da Vinci's efforts did not make important contributions to the technical advancement of flight.

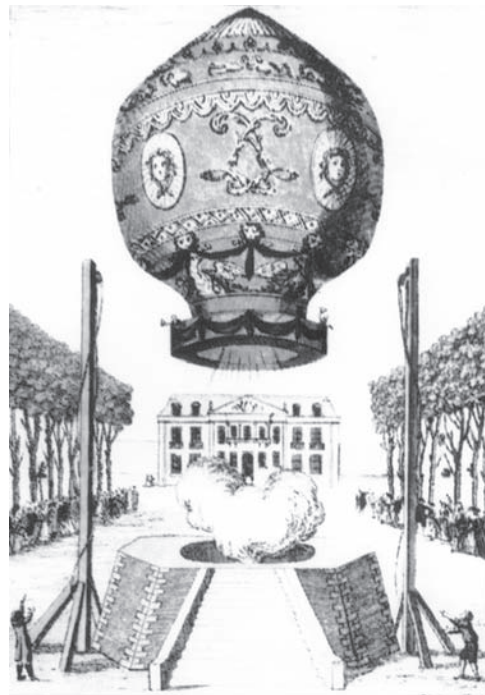
Human efforts to fly literally got off the ground on November 21, 1783, when a balloon carrying Pilatre de Rozier and the Marquis d'Arlandes ascended into the air and drifted 5 mi across Paris. The balloon was inflated and buoyed



**Figure 1.3** An ornithopter design by Leonardo da Vinci, 1486–1490.

up by hot air from an open fire burning in a large wicker basket underneath. The design and construction of the balloon were those of the Montgolfier brothers, Joseph and Etienne. In 1782 Joseph Montgolfier, gazing into his fireplace, conceived the idea of using the “lifting power” of hot air rising from a flame to lift a person from the surface of the earth. The brothers instantly set to work, experimenting with bags made of paper and linen, in which hot air from a fire was trapped. After several public demonstrations of flight without human passengers, including the 8-min voyage of a balloon carrying a cage containing a sheep, a rooster, and a duck, the Montgolfiers were ready for the big step. At 1:54 PM on November 21, 1783, the first flight with human passengers rose majestically into the air and lasted for 25 min (see Fig. 1.4). It was the first time in history that a human being had been lifted off the ground for a sustained period. Very quickly after this, the noted French physicist J. A. C. Charles (of Charles’ gas law in physics) built and flew a hydrogen-filled balloon from the Tuileries Gardens in Paris on December 1, 1783.

So people were finally off the ground! Balloons, or “aerostatic machines” as they were called by the Montgolfiers, made no real technical contributions to human



**Figure 1.4** The first aerial voyage in history: The Montgolfier hot-air balloon lifts from the ground near Paris on November 21, 1783.

(Source: *Library of Congress [LC-USZ62-15243]*.)



heavier-than-air flight. However, they served a major purpose in triggering the public's interest in flight through the air. They were living proof that people could really leave the ground and sample the environs heretofore exclusively reserved for birds. Moreover, balloons were the only means of human flight for almost 100 years.

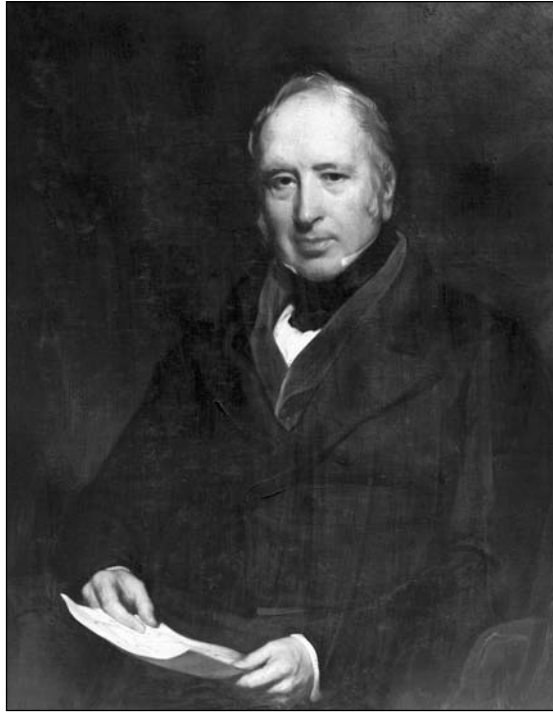
### 1.3 SIR GEORGE CAYLEY (1773–1857)—THE TRUE INVENTOR OF THE AIRPLANE

The modern airplane has its origin in a design set forth by George Cayley in 1799. It was the first concept to include a *fixed* wing for generating lift, another *separate* mechanism for propulsion (Cayley envisioned paddles), and a combined horizontal and vertical (cruciform) tail for stability. Cayley inscribed his idea on a silver disk (presumably for permanence), shown in Fig. 1.5. On the reverse side of the disk is a diagram of the lift and drag forces on an inclined plane (the wing). The disk is now preserved in the Science Museum in London. Before this time, thought of mechanical flight had been oriented toward the flapping wings of ornithopters, where the flapping motion was supposed to provide both lift and propulsion. (Da Vinci designed his ornithopter wings to flap simultaneously downward and backward for lift and propulsion.) However, Cayley is responsible for breaking this unsuccessful line of thought; he separated the concept of lift from that of propulsion and, in so doing, set into motion a century of aeronautical development that culminated in the Wright brothers' success in 1903. George Cayley is a giant in aeronautical history: He is the parent of modern aviation and was the first to introduce the basic configuration of the modern airplane. Let us look at him more closely.



**Figure 1.5** The silver disk on which Cayley engraved his concept for a fixed-wing aircraft, the first in history, in 1799. The reverse side of the disk shows the resultant aerodynamic force on a wing resolved into lift and drag components, indicating Cayley's full understanding of the function of a fixed wing. The disk is presently in the Science Museum in London.

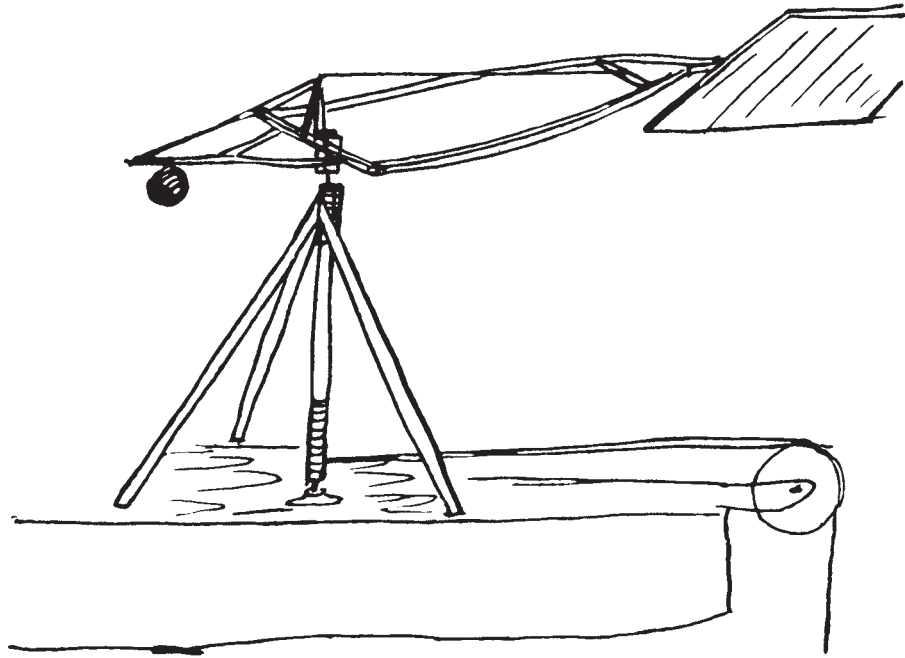
(Source: © Science and Society/SuperStock.)



**Figure 1.6** A portrait of Sir George Cayley, painted by Henry Perronet Briggs in 1841. The portrait now hangs in the National Portrait Gallery in London.  
(Source: © *Science and Society/SuperStock.*)

Cayley was born at Scarborough in Yorkshire, England, on December 27, 1773. He was educated at York and Nottingham and later studied chemistry and electricity under several noted tutors. He was a scholarly man of some rank, a baronet who spent much of his time on the family estate, called Brompton. A portrait of Cayley is shown in Fig. 1.6. He was a well-preserved person, of extreme intellect and open mind, active in many pursuits over a long life of 84 years. In 1825 he invented the caterpillar tractor, forerunner of all modern tracked vehicles. In addition, he was chairman of the Whig Club of York, founded the Yorkshire Philosophical Society (1821), cofounded the British Association for the Advancement of Science (1831), was a member of Parliament, was a leading authority on land drainage, and published papers dealing with optics and railroad safety devices. Moreover, he had a social conscience: He appealed for, and donated to, the relief of industrial distress in Yorkshire.

However, by far his major and lasting contribution to humanity was in aeronautics. After experimenting with model helicopters beginning in 1796, Cayley engraved his revolutionary fixed-wing concept on the silver disk in 1799 (see Fig. 1.5). This was followed by an intensive 10-year period of aerodynamic



**Figure 1.7** George Cayley's whirling-arm apparatus for testing airfoils.

investigation and development. In 1804 he built a whirling-arm apparatus, shown in Fig. 1.7, for testing airfoils; this was simply a lifting surface (airfoil) mounted on the end of a long rod, which was rotated at some speed to generate a flow of air over the airfoil. In modern aerospace engineering, wind tunnels now serve this function; but in Cayley's time the whirling arm was an important development that allowed the measurement of aerodynamic forces and the center of pressure on a lifting surface. Of course these measurements were not very accurate, because after a number of revolutions of the arm, the surrounding air would begin to rotate with the device. Nevertheless, it was a first step in aerodynamic testing. (Cayley did not invent the whirling arm; that honor belongs to the English military engineer Benjamin Robins in 1742.) Also in 1804, Cayley designed, built, and flew the small model glider shown in Fig. 1.8. This may seem trivial today, something that you might have done as a child; *but in 1804, it represented the first modern-configuration airplane of history*, with a fixed wing, and a horizontal and vertical tail that could be adjusted. (Cayley generally flew his glider with the tail at a positive angle of incidence, as shown in his sketch in Fig. 1.8.) A full-scale replica of this glider is on display at the Science Museum in London; the model is only about 1 m long.

Cayley's first outpouring of aeronautical results was documented in his momentous triple paper of 1809–1810. Titled “On Aerial Navigation” and published in the November 1809, February 1810, and March 1810 issues of Nicholson's



**Figure 1.8** The first modern-configuration airplane in history: Cayley’s model glider, 1804.

*Journal of Natural Philosophy*, this document ranks as one of the most important aeronautical works in history. (Note that the words *natural philosophy* in history are synonymous with physical science.) Cayley was prompted to write his triple paper after hearing reports that Jacob Degen had recently flown in a mechanical machine in Vienna. In reality, Degen flew in a contraption that was lifted by a balloon. It was of no significance, but Cayley did not know the details. In an effort to let people know of his activities, Cayley documented many aspects of aerodynamics in his triple paper. It was the first published treatise on theoretical and applied aerodynamics in history. In it, Cayley elaborated on his principle of the separation of lift and propulsion and his use of a fixed wing to generate lift. He stated that the basic principle of a flying machine is “to make a surface support a given weight by the application of power to the resistance of air.” He noted that a surface inclined at some angle to the direction of motion will generate lift and that a cambered (curved) surface will do this more efficiently than a flat surface. He also stated for the first time in history that lift is generated by a region of low pressure on the upper surface of the wing. The modern technical aspects of these phenomena are developed and explained in Chs. 4 and 5; however, stated by Cayley in 1809–1810, these phenomena were new and unique. His triple paper also addressed the matter of flight control and was the first document to discuss the role of the horizontal and vertical tail planes in airplane stability. Interestingly enough, Cayley went off on a tangent in discussing the use of flappers for propulsion. Note that on the silver disk (see Fig. 1.5) Cayley showed some paddles just behind the wing. From 1799 until his death in 1857, Cayley was obsessed with such flappers for aeronautical propulsion. He gave little attention to the propeller (airscrew); indeed, he seemed to have an aversion to rotating machinery of any type. However, this should not detract from his numerous positive contributions. Also in his triple paper, Cayley described the first successful full-size glider of history, built and flown without passengers by him at Brompton in 1809. However, there was no clue as to its configuration.

Curiously, the period from 1810 to 1843 was a lull in Cayley’s life in regard to aeronautics. Presumably he was busy with his myriad other interests and activities. During this period, he showed interest in airships (controlled balloons), as opposed to heavier-than-air machines. He made the prophetic statement that “balloon aerial navigation can be done readily, and will probably, in the order of things, come into use before mechanical flight can be rendered sufficiently safe and efficient for ordinary use.” He was correct; the first successful airship,