

Introduction to Aircraft Flight Mechanics: Performance, Static Stability, Dynamic Stability, and Classical Feedback Control

Thomas R. Yechout

with

Steven L. Morris

David E. Bossert

Wayne F. Hallgren



EDUCATION SERIES

Joseph A. Schetz

Series Editor-in-Chief

Virginia Polytechnic Institute and State University

Blacksburg, Virginia

Published by

American Institute of Aeronautics and Astronautics, Inc.

1801 Alexander Bell Drive, Reston, VA 20191-4344

Table of Contents

Preface	xiii
Acknowledgments	xv
Chapter 1 A Review of Basic Aerodynamics	1
1.1 Fundamental Concepts and Relationships	1
1.2 The Standard Atmosphere	13
1.3 Airfoil Fundamentals	15
1.4 Finite Wings	42
1.5 Aircraft Aerodynamics	47
1.6 Historical Snapshot—The AC-130H Drag Reduction Effort	53
References	55
Problems	56
Chapter 2 A Review of Basic Propulsion	59
2.1 Types of Propulsion Systems	59
2.2 Propulsion System Characteristics	64
2.3 Historical Snapshot—Aircraft Performance Modeling and the Learjet Model 35	76
Reference	78
Problems	78
Chapter 3 Aircraft Performance	81
3.1 Airspeed	81
3.2 Equations of Motion for Straight, Level, and Unaccelerated Flight	85
3.3 Thrust and Power Curves	87
3.4 Takeoff and Landing Performance	91
3.5 Gliding Flight	102
3.6 Climbs	108
3.7 Endurance	110
3.8 Range	116
3.9 Turn Performance and V - n Diagrams	127
3.10 Historical Snapshot	135
References	140
Problems	140

Chapter 4 Aircraft Equations of Motion	145
4.1 Aircraft Axis Systems	145
4.2 Coordinate Transformations	147
4.3 Aircraft Force Equations	153
4.4 Moment Equations	155
4.5 Longitudinal and Lateral-Directional Equations of Motion	164
4.6 Kinematic Equations	164
4.7 Historical Snapshot—Genesis 2000 Flight Simulator	169
Reference'	170
Problems	170
Chapter 5 Aircraft Static Stability	173
5.1 Static Stability Overview	173
5.2 Stability, Control Power, and Cross-Control Derivatives, and Control Deflection Sign Convention	174
5.3 Longitudinal Applied Forces and Moments	177
5.4 Longitudinal Static Stability	191
5.5 Lateral-Directional Applied Forces and Moments	202
5.6 Lateral-Directional Static Stability	215
5.7 Summary of Steady-State Force and Moment Derivatives	229
5.8 Historical Snapshot—The X-38 Mid-Rudder Investigation	230
References	233
Problems	233
Chapter 6 Linearizing the Equations of Motion	239
6.1 Small Perturbation Approach	239
6.2 Developing the Linearized Aircraft Equations of Motion	241
6.3 First-Order Approximation of Applied Aero Forces and Moments	244
6.4 First-Order Approximation of Perturbed Thrust Forces and Moments	279
6.5 Recasting the Equations of Motion in Acceleration Format	285
6.6 Historical Snapshot—The X-38 Parafoil Cavity Investigation	291
References	296
Problems	296
Chapter 7 Aircraft Dynamic Stability	303
7.1 Mass-Spring-Damper System and Classical Solutions of Ordinary Differential Equations	303
7.2 Root Representation Using the Complex Plane	316
7.3 Transforming the Linearized EOM to the Laplace Domain	321

TABLE OF CONTENTS

xi

7.4	Dyanmic Stability Guidelines	356
7.5	Cooper–Harper Ratings	371
7.6	Experimental Determination of Second-Order Parameters	372
7.7	Historical Snapshot—The A-10A Prototype Flight Evaluation	377
	References	380
	Problems	380
Chapter 8 Classical Feedback Control		389
8.1	Open-Loop Systems, Transfer Functions, and Block Diagrams	389
8.2	Closed-Loop Systems	392
8.3	Closed-Loop Analysis of a Second-Order System	394
8.4	Closed-Loop Transfer Functions	399
8.5	Time Response Characteristics	403
8.6	Root Locus Analysis	405
8.7	Historical Snapshot—The C-1 Autopilot	427
	Problems	428
Chapter 9 Aircraft Stability and Control Augmentation		433
9.1	Inner-Loop Stability and Control	433
9.2	Outer-Loop Autopilot/Navigation Control	444
9.3	Compensation Filters	451
9.4	Combined Systems	457
9.5	Historical Snapshot—The A-7D DIGITAC Digital Multimode Flight Control System Program	463
	References	469
	Problems	469
Chapter 10 Special Topics		473
10.1	System Type and Steady-State Error	473
10.2	Frequency Response	492
10.3	Digital Control	544
10.4	Advanced Control Algorithms	549
10.5	Reversible and Irreversible Flight Control Systems	551
10.6	Spins	554
10.7	Historical Snapshot—The F-16 Fly-by-Wire System	558
	Problems	567
Appendix A Conversions		571
Appendix B Properties of the U.S. Standard Atmosphere		573
Appendix C Airfoil Data		577
Appendix D T-38 Performance Data		589

Appendix E	Selected Laplace Transforms	603
Appendix F	Cramer's Rule	605
Appendix G	Development of Longitudinal and Lateral-Directional Transfer Functions	609
Appendix H	Stability Characteristics of Selected Aircraft	613
Bibliography	623
Index	625
Series listing	631